HYDROLOGIC MONITORING OF SELECTED STREAMS IN COAL FIELDS OF CENTRAL AND SOUTHERN UTAH—SUMMARY OF DATA COLLECTED, AUGUST 1978-SEPTEMBER 1984

By Don Price and Gerald G. Plantz

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 86-4017

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DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

Most values are given in this report in inch-pound units. For those readers who may prefer to use metric units, the conversion factors for the terms used in this report are listed below. Multiply the inch-pound unit by the factor to obtain the metric equivalent.

Inch-pound Unit	Abbreviation	Conversion factor	Metric unit
Acre		0.4047	Square hectometer
Acre-foot	acre-ft	0.001233	Cubic hectometer
Cubic foot per second	ft^3/s	0.02832	Cubic meter per second
Cubic foot per second per mile	$(ft^3/s)/mi$	0.017609	Cubic meter per second per kilometer
Cubic foot per second per square mile	$(ft^3/s)/mi^2$	0.01093	Cubic meter per second per square kilometer
Foot	ft	0.3048	Meter
Gallon per minute	gal/min	0.06309	Liter per second
Inch	in.	25.40	Millimeter
		2.540	Centimeter
Mile	mi	1.609	Kilometer
Square mile	mi^2	2.590	Square kilometer
Ton (short, 2,000 pounds)		0.9072	Megagram (metric ton)

Chemical concentration and water temperatures are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (ug/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is about the same as for concentrations in parts per million.

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$^{\circ}F = 1.8(^{\circ}C) + 32.$$

Hydrologic Monitoring of Selected Streams in Coal Fields of Central and Southern Utah--Summary of Data Collected, August 1978-September 1984

by Don Price and Gerald G. Plantz

ABSTRACT

The U.S. Geological Survey conducted a coal-hydrology monitoring program in coal-field areas of central and southern Utah during August 1978-September 1984. The monitoring was implemented to determine possible hydrologic impacts of future mining and to provide a better understanding of the hydrologic systems of the coal-resource areas monitored. Data were collected at 19 gaging stations--18 stations in the Price, San Rafael, and Dirty Devil River basins, and 1 in the Kanab Creek basin. Streamflow data were collected continuously at 11 stations and seasonally at 5 stations. At the other three stations streamflow data were collected continuously during the 1979 water year and then seasonally for the rest of their periods of record.

Types of data collected at each station included quantity and quality of streamflow; suspended-sediment concentrations; and descriptions of stream-bottom sediments, benthic-invertebrate, and phytoplankton samples. Also, base-flow measurements were made annually upstream from 12 of the gaging stations.

Stream-bottom sediment sampled at nearly all the monitoring sites contained small to moderate quantities of coal, which may be attributed chiefly to pre-monitoring mining. Streamflow sampled at several sites contained large concentrations of sulfate and dissolved solids. Also, concentrations of various trace elements at 10 stations, and phenols at 18 stations, exceeded the criteria of the U.S. Environmental Protection Agency for drinking water. This may be attributed to contemporary (water years 1979-84) mine-drainage activities.

The data collected during the complete water years (1979-84) of monitoring do provide a better understanding of the hydrologic systems of the coal-field areas monitored. The data also provide a definite base by which to evaluate hydrologic impacts of continued or increased coal mining in those areas.

INTRODUCTION

Purpose and Scope

The purpose of this report is to summarize selected hydrologic data collected from August 1978 to September 1984 in coal-field areas of central and southern Utah. Virtually all data have been published in the U.S. Geological Survey annual report series "Water resources data for Utah." (See, for example, ReMillard and others, 1985.) They are also available in the files of the U.S. Geological Survey.

Collection of the data was started in August 1978, when the U.S. Geological Survey installed 12 gaging stations downstream from active underground coal mines and areas leased for underground coal mining in the Wasatch Plateau, Book Cliffs, and Emery coal fields of central Utah (pl. 1). The 12 stations were part of a network designed to help define the hydrology of the coal-resource areas and to provide baseline data that could be used to determine the hydrologic impacts of future coal mining. Each station was established to monitor quantity and quality of the streamflow, fluvial sediment, and benthic invertebrates. During August 1978-September 1979, the monitoring also included base-flow measurements at 52 sites, generally upstream from the 12 gaging stations. Water samples for chemical analyses also were collected at 13 of the sites used for base-flow measurements. The data collected from the network during August 1978-September 1979 were published by the U.S. Geological Survey (1980) and are summarized in a report by Lines and Plantz (1981).

During October 1979-September 1984 the monitoring network was modified in several ways. Some gaging stations were discontinued, and others were added to the network. One of the stations added (09403670) was in the Kanab Creek basin, in the Alton coal-field area in southern Utah (pl. 1).

Data collection during October 1979-September 1984 varied somewhat from data collection during the early period of monitoring. For example, in water year 1981 (the year ending September 30, 1981) samples were collected for determinations of phytoplankton instead of benthic invertebrates, and water analyses included determinations of radiochemicals in addition to standard dissolved chemical ions (table 1). The radiochemical data are not summarized in this report, but they are included in U.S. Geological Survey (1982). Base-flow measurements (generally two sets a year) were continued upstream from most gaging stations (mostly through August 1981).

The monitoring program was discontinued September 30, 1984, although several gaging stations remained in operation for special projects. When the monitoring was started in August 1978, 23 coal mines were active in the Wasatch Plateau, Book Cliffs, and Emery coal fields, and they produced about 9.2 million tons of coal that year. There was no mining in the Alton coal field (table 2). During the monitoring period, the annual coal production in the Wasatch Plateau, Book Cliffs, and Emery coal fields increased to as much as 17.6 million tons (in 1982), but there was only some exploratory drilling in the Alton coal field.

Previous Investigations

The U.S. Geological Survey conducted many hydrologic studies in the areas of central and southern Utah coal-fields prior to, and during the monitoring program summarized in this report. Those studies resulted in many reports that deal with various aspects of hydrology. Lines and others (1983) gives a complete listing of those hydrologic reports for the central Utah coal-fields area, and Price and others (1987) gives a complete listing of those hydrologic reports for the southern Utah coal-fields area.

Table 1.--Gaging stations in the coal-field areas of central and southern Utah
(see plate 1 for locations of stations)

Station number: See text for explanation of numbering system.
Water years and data collected: Solid bar represents complete daily record, open bar indicates seasonal record only. Letters under bars indicate types of data collected in addition to rates of streamflow: B, benthic invertebrates; C, general chemical quality; P, phytoplankton; R, radiochemical determinations; and S, fluvial sediment. (See ReMillard and others, 1985, and other reports in the same series.)

Station		Water years and data collected					
Number	Name	1979	1980	1981	1982	1983	1984
	COLORADO RIVER BASIN						
	GREEN RIVER BASIN						
	PRICE RIVER:						
	Mud Creek:						
09310600	Eccles Canyon near Scofield		BCS	CPRS	S	CS	CS
09310700	Mud Creek below Winter Quarters Canyon, at Scofield	BCS	BCS	CPRS		CS	CS
09312900	Willow Creek at Castle Gate		BCS	CPRS			
09313000[1]	Price River near Heiner		BCS	CPRS			
09313040	Spring Canyon below Sowbelly Gulch, at Helper	BCS	BCS	CPRS			
09313965	Coal Creek near Helper	BCS	BCS	CPRS			
09313975	Soldier Creek below mine, near Wellington	BCS	BCS	CPRS	BC	C	C
09313985	Dugout Creek near Sunnyside		BCS	CPRS			
09314340	Grassy Trail Creek at Sunnyside	BCS	BCS	CPRS	BC	C	C
09314374	Horse Canyon near Sunnyside	BCS	BCS	CPRS			
	SAN RAFAEL RIVER:						
	Huntington Creek:						
09317919	Crandall Canyon at mouth, near Huntington	BCS	BCS	CPRS	BC	C	C
09317920	Tie Fork near Huntington	BCS	BCS	CPRS			
09317997	Huntington Creek near Huntington		BCS	CPRS			
09318000[1]	Huntington Creek near Huntington	BCS					
09324200	Cottonwood Creek above Straight Canyon, near Orangeville	BCS	BCS	CPRS			
	DIRTY DEVIL RIVER BASIN						
	MUDDY CREEK:						
	Quitchupah Creek:						
09331850	Convulsion Canyon near Emery			CPRS	BC	C	C
09331900	Quitchupah Creek near Emery	BCS	BCS	CPRS			
09331950	Christiansen Wash near Emery	BCS	BCS	CPRS	BC	C	C
	KANAB CREEK BASIN						
	JOHNSON WASH:						
	Skutumpah Creek:						
09403670	Thompson Creek near Glendale			CPRS			

[1]Previously operated as part of the statewide network (see text).

Table 2.--Annual coal production by coal field, 1978-83
[Production in thousands of short tons, from unpublished data of Utah Geological and Mineral Survey.]

Coal field	Number of producing mines	1978 Production	Number of producing mines	1979 Production	Number of producing mines	1980 Production	Number of producing mines	1981 Production	Number of producing mines	1982 Production	Number of producing mines	1983 Production
Wasatch Plateau	17	6,499	17	8,640	17	9,875	-	10,190	-	12,873	26	10,248
Book Cliffs	4	2,207	4	2,725	4	2,993	4	3,365	4	3,900	4	1,646
Emery	2	497	2	732	2	761	2	650	2	852	1	88
Alton	0	0	0	0	0	0	0	0	0	0	0	0
Totals (rounded)	23	9,200	23	12,100	-	13,600	-	14,200	-	17,600	31	12,000

Gaging-Station Numbering System

Gaging stations operated by the U.S. Geological Survey are assigned an eight-digit number as shown on plate 1 and table 1. The first two digits, 09, indicate that the stations are on streams in the Colorado River Basin. The next six digits indicate the relative downstream order of the stations in the Basin. Thus, station 09310600 (table 1) is the farthest upstream station in the Colorado River Basin in the area of this report (pl. 1), and station 09403670 (table 1) is the farthest downstream station in the Basin in the area of this report.

PHYSIOGRAPHIC, GEOLOGIC, AND HYDROLOGIC SETTING

Central Utah Coal-Fields Area

Much of the information given below is taken from reports by Lines and Plantz (1981, p. 2-6) and Lines and others (1983). The reader is referred to those reports for additional information about the physiographic, geologic, and hydrologic setting of the central Utah coal-fields area.

The area consists largely of high plateaus dissected by deep, winding canyons. Land-surface altitudes range from about 6,000 to 11,000 feet in the Wasatch Plateau coal-field area, from about 6,000 to 10,000 feet in the Book Cliffs coal-field area, and from about 6,000 to 8,000 feet in the Emery coal-field area. Local relief commonly exceeds 1,000 feet in the Wasatch Plateau and Book Cliffs coal-field areas and is generally less than 800 feet in the Emery coal field.

Rocks that crop out in the central Utah coal-fields area consist chiefly of sandstone, mudstone, and shale as shown diagrammatically in figure 1. The Blackhawk Formation of Cretaceous age is the principal coal-bearing formation in the Wasatch Plateau and Book Cliffs coal fields, and the Ferron Sandstone Member of the Mancos Shale of Cretaceous age is the principal coal-bearing formation in the Emery coal field. Coal in the Blackhawk is mineable only by underground mining; whereas coal in the Ferron Sandstone Member is mineable by both surface and underground mining, but mostly by underground mining.

Average annual precipitation varies from about 10 to 40 inches on the Wasatch Plateau coal-field area, from about 10 to 20 inches on the Book Cliffs coal-field area, and from about 8 to 30 inches on the Emery coal-field area. Most of the annual precipitation falls during October-April, chiefly as snow. Some of the snow accummulates on the high Wasatch and West Tavaputs Plateaus, and the meltwater is a principal source of streamflow during early summer. May-September precipitation generally falls during thunderstorms or cloudbursts which commonly result in considerable local flooding.

Total mean annual runoff from the central Utah coal-fields area ranges from less than 1 inch (less than 55 acre-feet per square mile) in the lower altitudes to about 15 inches (about 800 acre-feet per square mile) in the higher altitudes of the Wasatch Plateau. Most of the runoff is to the Price, San Rafael, and Dirty Devil Rivers. The Price and San Rafael flow into the Green River, a major tributary of the Colorado River; the Dirty Devil flows directly into the Colorado at Lake Powell. (See index map of Utah on Plate 1.)

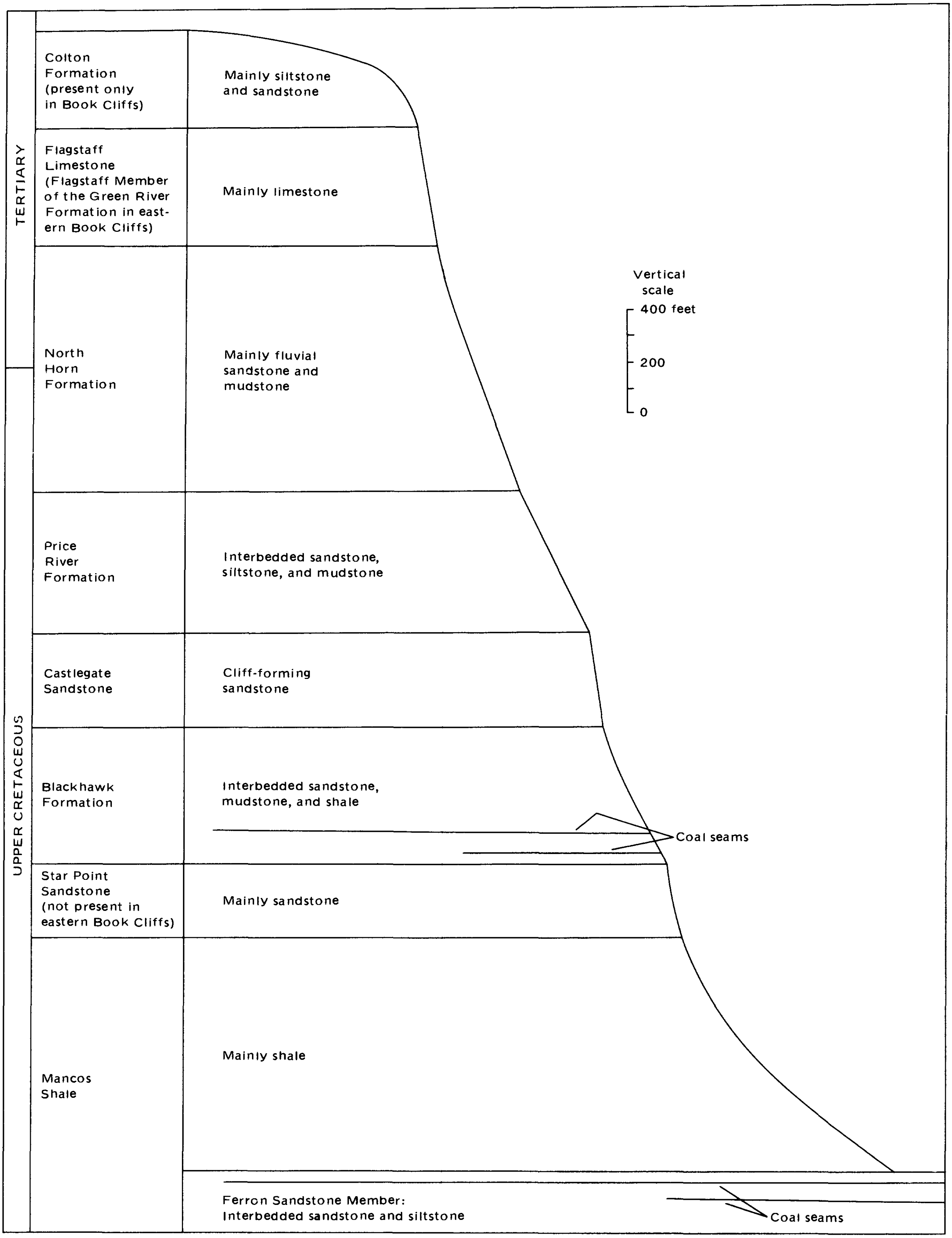

Figure 1.—Diagrammatic section of geologic formations in the coal fields of central Utah (from Lines and Plantz, 1981, fig. 1).

Dissolved-solids concentrations in streamflow in the central Utah coal-fields area generally are less than 300 milligrams per liter in headwaters of the smaller higher-altitude tributary streams during both high- and low-flow periods. The concentrations, however, commonly exceed 3,000 milligrams per liter in the downstream reaches of some streams, especially during periods of low flow. The principal source of the larger dissolved-solids concentrations is the Mancos Shale and surficial deposits derived from the Mancos, which contain considerable gypsum and other comparatively easily dissolved minerals. Those minerals are dissolved and carried to the streams by overland runoff, ground water, and ground water derived from irrigation-return flows.

Water occurs in virtually all the rocks that underly the central Utah coal fields. The Flagstaff Limestone of Tertiary age and North Horn Formation of Cretaceous and Tertiary age discharge water to numerous springs in the higher parts of the Wasatch and West Tavaputs Plateaus. The Blackhawk Formation, Star Point Sandstone of Cretaceous age, and the Ferron Sandstone Member of the Mancos Shale discharge water to mine workings and to several springs. The Ferron Sandstone Member also is tapped by several wells near the town of Emery. Seepage from some of the formations helps to sustain the base flow of the streams.

Dissolved-solids concentrations in the ground water vary considerably depending on altitude and geologic formation. Springs that discharge from the Flagstaff Limestone and North Horn Formation high on the Wasatch Plateau generally contain less than 500 milligrams per liter of dissolved solids. Water that discharges from the Mancos Shale in the lower altitudes generally contains more than 3,000 milligrams per liter of dissolved solids. Mine water from the Blackhawk Formation and Star Point Sandstone generally contains 400 to 1,000 milligrams per liter of dissolved solids, but mine water from the Ferron Sandstone Member contains as much as 5,000 milligrams per liter of dissolved solids.

Alton Coal-Field Area

The following discussion is taken partly from a report by Price and others (1987). Readers are referred to that report for additional information about the physiographic, geologic, and hydrologic setting of the Alton coal-field area and adjacent coal fields of southern Utah.

The Alton coal-field area is made up largely of benches, terraces, and high plateaus which are dissected by deep, narrow canyons. Land-surface altitudes range from about 5,000 feet on the lower benches to more than 9,000 feet on the Paunsaugunt plateau, and local relief commonly exceeds 1,000 feet.

Rocks that range in age from Jurassic to Quaternary are exposed in the area. They are mostly of continental sedimentary origin, consisting chiefly of shale, siltstone, and sandstone, as shown diagrammatically in figure 2. Those formations are mantled in many places by stream-valley alluvium and other unconsolidated deposits of Quaternary age. The principal coal-bearing formation is the Dakota Sandstone of Cretaceous age, but the Tropic Shale of Cretaceous age also contains some coal seams. Both formations contain considerable gypsun and other comparatively easily dissolved minerals.

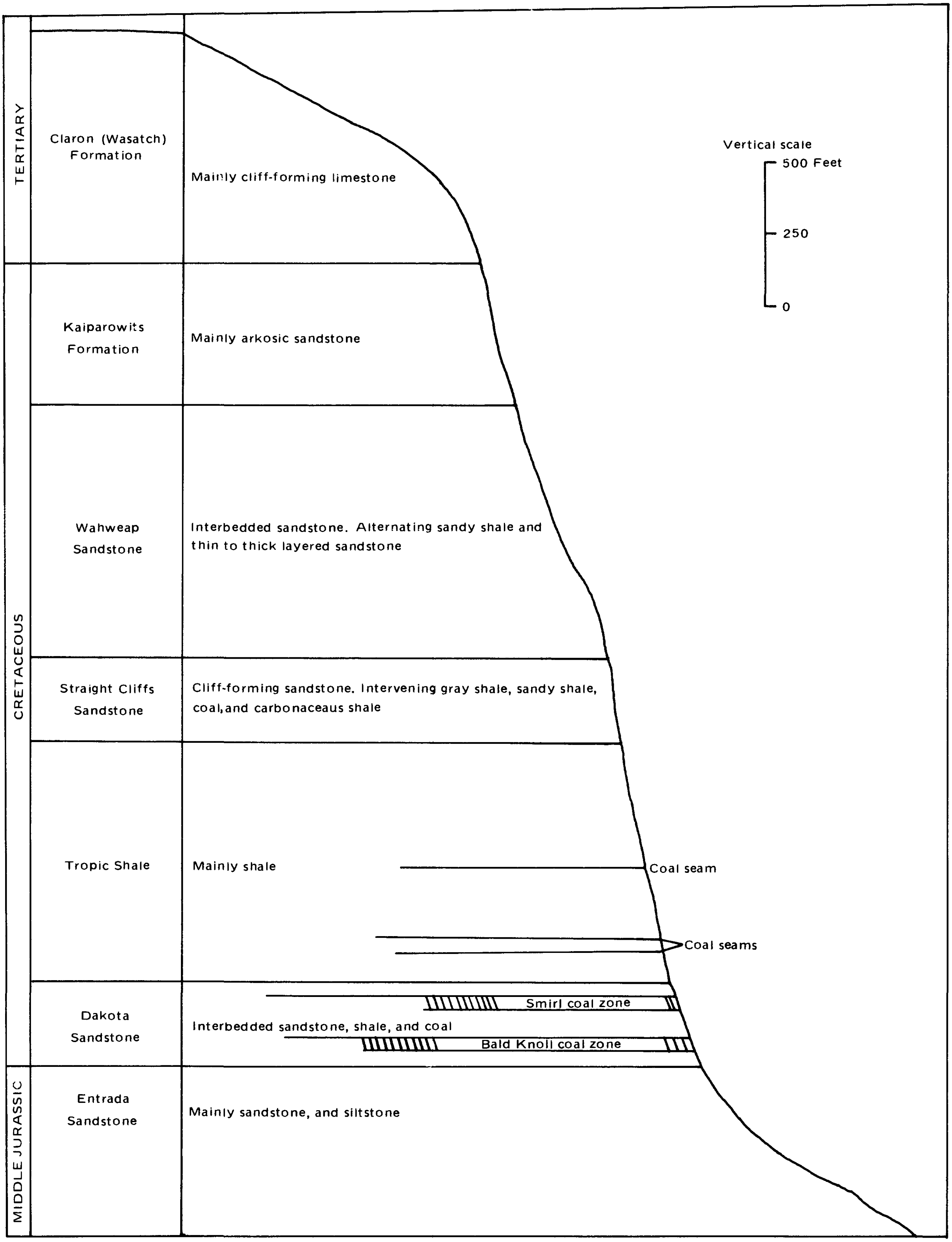

Figure 2.—Diagrammatic section of geologic formations in the Alton coal-field area (adapted from Doelling and Graham, 1972, fig. 6).

Average annual precipitation in the Alton coal-field area ranges from less than 12 inches in the lower altitudes to about 25 inches in the higher altitudes. Most of the precipitation falls during October-April, generally occurs as snow which accummulates in the higher altitudes. Those high-altitude snowpacks are the principal source of streamflow in the area. May-September precipitation commonly falls during thunderstorms or cloudbursts which can result in local flash floods.

Average annual runoff from the area ranges from less than 0.5 inch (less than 30 acre-feet per square mile) in the lower altitudes to about 5 inches (about 267 acre-feet per square mile) in the higher altitudes. The high-altitude runoff is produced chiefly by snowmelt, whereas the low-altitude runoff is produced chiefly by local thunderstorms. Most of the runoff from the area is to Kanab Creek, which discharges directly into the Colorado River about 50 miles south of the Arizona-Utah State line. Some runoff from the area is to the Virgin and Paria Rivers (in the Colorado River Basin) and to the Sevier River (in the Great Basin).

Dissolved-solids concentrations in the streamflow in headwater areas are generally less than 500 milligrams per liter during periods of both high and low flow. The concentrations generally exceed 1,000 milligrams per liter in some lower stream reaches, chiefly during periods of low flow. The principal source of the larger dissolved-solids concentrations is the Tropic Shale. Minerals are dissolved from the Tropic Shale and carried to the streams by overland runoff and by ground water that seeps through the shale.

Water occurs in virtually all formations that underly the Alton coal-field area. Most of the exposed formations discharge water to springs in the area, but they probably would not yield more than about 50 gallons per minute to individual wells. The Navajo Sandstone of Triassic(?) and Jurassic age, which is not exposed in the area, is a highly-productive regional aquifer in southern Utah. It discharges water to many springs along Kanab Creek south of the Alton coal field, and it is tapped by a number of irrigation wells that yield as much as 1,000 gallons per minute several miles south of the Alton coal field. Within the coal field, however, the Navajo lies beneath several hundred to more than 1,000 feet of younger formations.

Dissolved-solids concentrations in ground water in the Alton coal-field area vary considerably depending mainly on altitude and the geologic formation. Springs that discharge from the Wasatch Formation in the high plateaus generally contain less than 500 milligrams per liter of dissolved solids. Water in the Tropic Shale commonly contains more than 3,000 milligrams per liter of dissolved solids. Water in the other exposed formations generally contains 500 to 2,000 milligrams per liter of dissolved solids, the smaller concentrations occurring in the higher altitudes.

PRICE RIVER BASIN

Mud Creek and Eccles Canyon Creek

Mud (Pleasant Valley) Creek originates on the Wasatch Plateau at an altitude of about 9,600 feet in an area directly underlain by the Flagstaff Limestone. The stream descends about 1,600 feet to where it enters Pleasant Valley near the community of Clear Creek. From that point it meanders northward through Pleasant Valley and enters Scofield Reservoir (source of the Price River) at about 7,600 feet. Station 09310700 (pl. 1 and table 1) is about 1 mile upstream from Scofield Reservoir at 7,720 feet. Eccles Canyon creek is one of several streams that enter Mud Creek from the west between the community of Clear Creek and Scofield Reservoir. Station 09310600 (pl. 1 and table 1) was established near the mouth of Eccles Canyon at 7,980 feet.

Coal mining was started in the Mud Creek basin during the late 1800's and has continued intermittently to the present (1985). During the monitoring period at station 09310600 and 09310700, several mines were active in the Mud Creek basin. As noted by Lines and Plantz (1981, p. 6), all the mines produce water, but most of the water produced is used and consumed in the mining operations. It is not known how much water is discharged from mines to Mud Creek or its tributaries; however, such discharge generally seems to be of good chemical quality. For example, the dissolved-solids concentration of water discharged from the Utah No. 2 Mine (pl. 1) in September 1975 was 482 milligrams per liter. (See Lines and Plantz, 1981, p. 6.)

Eccles Canyon creek enters Mud Creek about 3 miles upstream from station 09310700 (pl. 1). The annual mean flow in Eccles Canyon creek, where it is gaged at station 09310600, ranged from 1.64 cubic feet per second in water year 1981 to 6.78 cubic feet per second in water year 1984 (table 3). Most of the annual flow in Eccles Canyon creek is from late April to early July, as shown in figure 3. The maximum recorded peak flow at station 09310600 was 71.0 cubic feet per second on May 23, 1984 (table 3).

The chemical quality of streamflow in Eccles Canyon is generally good, that is, the water is chemically suitable for most common uses. Dissolved-solids concentrations in 46 samples collected at station 09310600 during the 1980-84 water years ranged from 160 to 490 milligrams per liter with a mean of 293 milligrams per liter (table 4). Calcium, magnesium, and bicarbonate were the dominant ions found in the samples. With the exception of manganese, concentrations of trace elements that were analyzed were smaller than the criteria of the U.S. Environmental Protection Agency (1976) for drinking water supplies[1]. The mean concentration of manganese for 28 samples was 67 micrograms per liter, compared to a criterion of 50 micrograms per liter. The phenol concentrations in some samples exceeded the criterion of 1 microgram per liter (U.S. Environmental Protection Agency, 1976, p. 183).

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[1]The criteria of the U.S. Environmental Protection Agency (1976) are in total ions, whereas the values listed in tables 4-21 in this report are in dissolved ions.

page 12 follows

Table 3.--**Summary of gaging-station records for the coal-field areas of central and southern Utah.** (See ReMillard

Number	Station	Period of record used (water years)	Drainage Basin: Area (square miles)	Drainage Basin: Altitude at gage (feet)	Annual mean flow (cubic feet per second), Water years: 1979	1980	1981	1982	1983	1984
09310600	Eccles Canyon near Scofield	1980-84	5.5	7,980	--	4.02	1.64	4.61	6.47	6.78
09310700	Mud Creek below Winter Quarters Canyon, at Scofield	1979-84	29.1	7,720	8.51	18.6	5.52	19.0	26.8	30.7
09312900	Willow Creek at Castle Gate	1980-81	77.4	6,100	--	17.3	4.58	--	--	--
09313000(1)	Price River near Heiner	1935-69, 1980-81	415	6,000	--	196	73.8	--	--	--
09313040	Spring Canyon below Sowbelly Gulch, at Helper	1979-81	23.0	6,110	.12	.35	.41	--	--	--
09313965	Coal Creek near Helper	(2)1979-81	25.3	6,370	--	--	--	--	--	--
09313975	Soldier Creek below mine, near Wellington	(2)1979-84	17.7	6,650	--	--	--	--	--	--
09313985	Dugout Creek near Sunnyside	(2)1980-81	5.8	6,960	--	--	--	--	--	--
09314340	Grassy Trail Creek at Sunnyside	1979-84	40.1	6,540	7.02	11.3	2.43	7.25	24.2	7.16
09314374	Horse Canyon near Sunnyside	1979-81	12.5	6,180	.40	.43	.29	--	--	--
09317919	Crandall Canyon at mouth, near Huntington	(4)1979-84	5.7	7,350	2.19	--	--	--	--	--
09317920	Tie Fork near Huntington	(4)1979-81	11.7	7,400	2.04	--	--	--	--	--
09317997	Huntington Creek near Huntington	1980-81	181	6,450	--	112	63.0	--	--	--
09318000(1)	Huntington Creek near Huntington	1910-17, 1922-29, 1931-73, 1978-79	190	6,210	77.4	--	--	--	--	--
09324200	Cottonwood Creek above Straight Canyon, near Orangeville	(4)1979-81	21.9	6,940	.87	--	--	--	--	--
09331850	Convulsion Canyon near Emery	(2)1981-84	21.5	7,120	--	--	--	--	--	--
09331900	Quitchupah Creek near Emery	1979-81	104	5,900	6.73	10.8	7.76	--	--	--
09331950	Christiansen Wash near Emery	1979-84	13.6	5,920	2.66	3.32	2.09	3.54	5.80	6.42
09403670	Thompson Creek near Glendale	(2)1981	19.2	6,050	--	--	--	--	--	--

(1)Previously operated as part of the statewide network (see text).

(2)Seasonal record. (See table 1.)

(3)No flow for parts of few to many days most years.

(4)Continuous record for 1979 water year, seasonal record for remainder of period. (See table 1.)

and others, 1985, and earlier reports in the same series for complete records.)

Average Annual Flow (Cubic feet per second)	Average Annual Flow (Cubic feet per second per square mile)	Years of complete record	Extreme flow recorded for period of record used (cubic feet per second): Maximum	Date	Minimum	Date
4.70	0.85	5	71.0	5-23-84	0.62	1-10-80
18.2	.62	6	389	5-21-84	1.4	9- 8-79
--	--	2	210	5-23-80	.60	1-13,26-80
112	.30	37	9,340 1,100	9-13-40 5-31-80	.40 3.6	8-21-61 11-11,14-80
.29	.01	3	271	7-12-81	.02	7- 2-79
--	--	--	458	8-13-79	0	(3)
--	--	--	472	9-23-81	.08	8- 5-81
--	--	--	127	9- 5-81	0	(3)
9.89	.25	6	631	5-31-83	0	(3)
--	--	3	93.0	9- 5-81	0	(3)
--	--	1	97.0	5-24-84	.24	3-10-79
--	--	1	29.0	4-30-80	.17	3-10-79
--	--	2	1,020	6-11-80	3.0	2-2,5-81
96.3	.51	61	2,500 684	8- 2-30 8-13-79	.87 .87	11-26-76 11-28-78
--	--	1	22.0	6- 5-80	0	(3)
--	--	--	34.0	7-30-84	.01	9-22,25-82
--	--	3	2,590	9- 8-81	.66	8-10-81
3.97	.30	6	1,540	9- 8-81	.29	7-21,23-81
--	--	--	1,030	8-14-81	.23	7-31,8-9-81

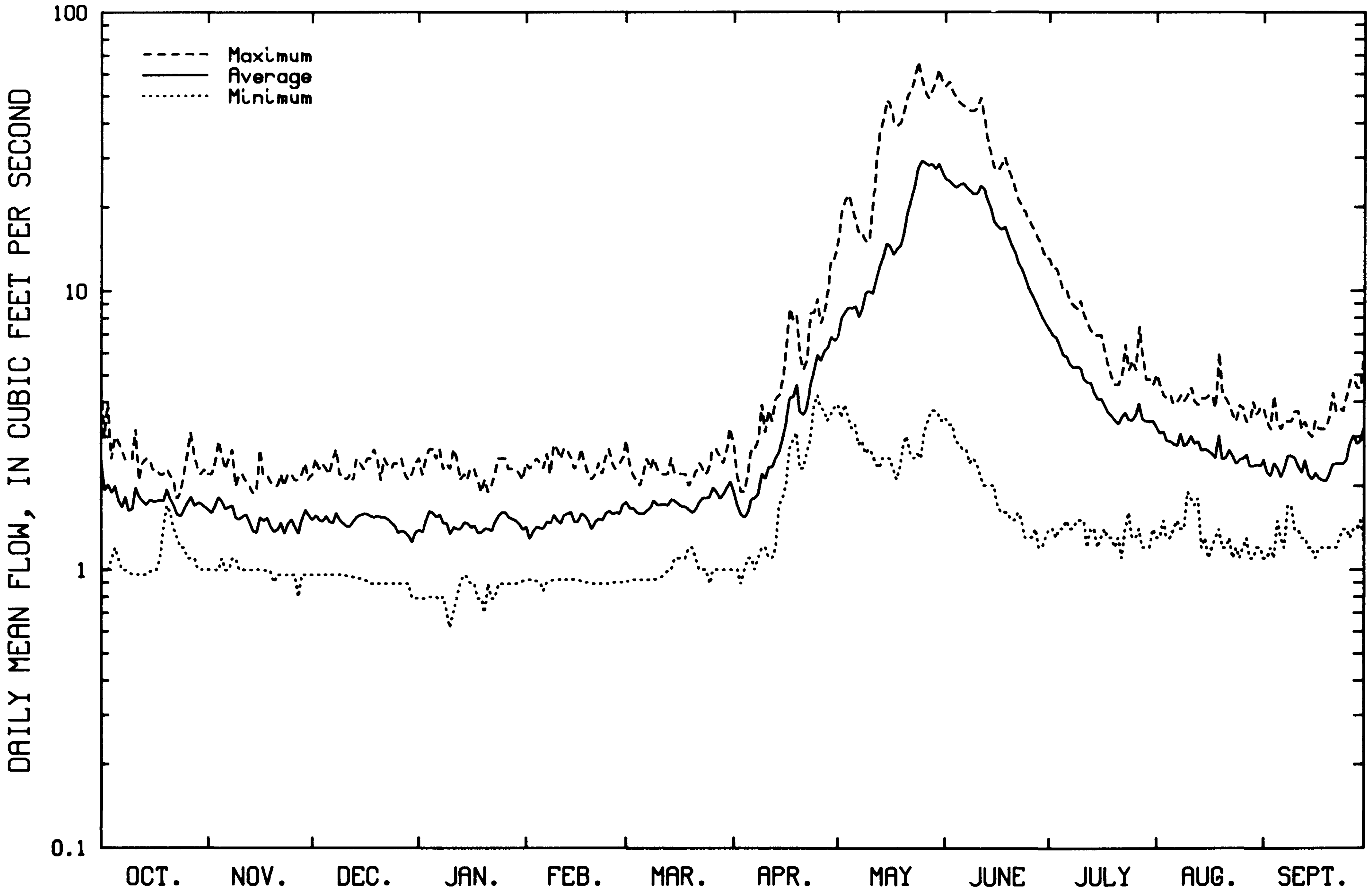

Figure 3.—Maximum, average, and minimum daily mean flow of Eccles Canyon creek at station 09310600, water years 1980-84.

Table 4.—Summary of chemical analyses of streamflow in Eccles Canyon creek at station 09310600, water years 1980–84

[< indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	47	6.0	0.82-53
Water temperature (degrees Celsius)	46	7.0	.0-14.5
Specific conductance (microsiemens per centimeter at 25° Celsius)	47	511	285-880
pH (units)	42	--	7.6-8.6
Sodium-adsorption ratio	33	.13	.1-.3
Milligrams per liter			
Dissolved solids, sum of constituents	46	293	160-490
Oxygen, dissolved (O_2)	37	9.0	7.6-10.3
Carbon dioxide, dissolved (CO_2)	25	2.7	.9-5.3
Alkalinity ($CaCO_3$)	31	237	130-300
Bicarbonate (HCO_3)[1]	25	296	200-360
Carbonate (CO_3)[1]	25	1.6	.0-8.0
Nitrogen, dissolved (N)	19	.90	.16-3.4
Nitrogen, organic dissolved (N)	8	.74	.00-2.2
Nitrogen, ammonia dissolved (N)	23	--	<.01-.100
Nitrogen, nitrite dissolved (N)	8	--	<.014
Nitrogen, nitrate dissolved (N)	8	--	<.05-1.2
Nitrogen, nitrite + nitrate dissolved (N)	30	--	<.01-1.2
Phosphorus, dissolved (P)	26	--	<.01
Phosphorus, ortho phosphates dissolved (P)	17	--	<.001-.100
Carbon, organic dissolved (C)	14	5.9	1.2-39
Hardness, (as $CaCO_3$)	33	272	150-440
Hardness, (as noncarbonate, $CaCO_3$)	31	39.9	.0-170
Calcium, dissolved (Ca)	43	69.3	43-85
Magnesium, dissolved (Mg)	43	23.4	9.4-58
Sodium, dissolved (Na)	43	5.1	2.5-12
Potassium, dissolved (K)	38	2.1	1.1-3.1
Chloride, dissolved (Cl)	43	10.0	2.0-110
Sulfate, dissolved (SO_4)	46	42.0	13.0-9.4
Fluoride, dissolved (F)	29	.19	.10-.60
Silica, dissolved (SiO_2)	38	6.7	5.1-10

Table 4.—Summary of chemical analyses of streamflow in Eccles Canyon creek at station 09310600, water years 1980-84--Continued

	Properties and constituents	No. of analyses	Mean	Minimum-maximum
Milligrams per liter	Arsenic, dissolved (As)	18	—	<1-1
	Barium, dissolved (Ba)	5	--	<100-100
	Boron, dissolved (B)	29	—	<10-3,600
	Cadmium, dissolved (Cd)	16	--	<1-2
	Chromium, dissolved (Cr)	20	—	<20
	Copper, dissolved (Cu)	15	--	<10
	Iron, dissolved (Fe)	39	—	<10-200
	Lead, dissolved (Pb)	19	--	<1-2
	Lithium, dissolved (Li)	9	—	<10-30
	Manganese, dissolved (Mn)	28	67	16-110
	Mercury, dissolved (Hg)	13	—	<.1
	Nickel, dissolved (Ni)	7	--	<1-3
	Selenium, dissolved (Se)	17	—	<1-2
	Strontium, dissolved (Sr)	9	--	<10-230
	Zinc, dissolved (Zn)	20	—	<3-180
	Phenols	11	--	<1-8

[1]Fixed-end-point determined by titration in the field.

Suspended-sediment concentrations in 90 streamflow samples collected at station 09310600 ranged from 10 milligrams per liter January 13, 1981 to 45,100 milligrams per liter on May 30, 1983. Instantaneous suspended-sediment loads determined from the suspended-sediment samples concentrations and flow data are as follows:

Water year	Suspended-sediment load (tons/day)	
	Minimum	Maximum
1980	0.16	228
1981	.03	6.9
1982	.12	206
1983	(1) .21	(1) 419
1984	(1) .11	(1) 551

(1)Determined from additional samples collected for another project.

Benthic invertebrates and phytoplankton may be indicators of the general quality of streamflow and stream-bottom habitats. Good diversity (uniform distribution of organisms) in benthic-invertebrate samples generally reflects unpolluted stream-bottom conditions. Also, good diversity of phytoplankton and a predominance of green algae may reflect generally good chemical quality of the water. A predominance of blue-green algae may be indicative of relatively large dissolved-solids concentrations (including nutrients) in the water. Two benthic invertebrate samples collected at station 09310600 in the 1980 water year had fairly good diversity--that is, a fairly uniform distrubution of individual organisms. (See U.S. Geological Survey, 1981, p. 231.) Four phytoplankton samples collected at the same site during water year 1981 had a good representation of green algae with good diversity (U.S. Geological Survey, 1982, p. 228). Blue-green algae, however, were well represented in the samples collected during August when the streamflow was relatively warm and its dissolved-solids concentration was relatively large.

Station 09310700 on Mud Creek was operated continuously during the 1979-84 water years (table 1). Annual mean flow during that period ranged from 5.52 cubic feet per second in water year 1981 to 30.7 cubic feet per second in water year 1984 and averaged 18.2 cubic feet per second (table 3). Most of the annual flow occurs from early May to mid July, as shown in figure 4, and this flow is chiefly due to snowmelt. The maximum peak discharge recorded at station 09310700 was 389 cubic feet per second on May 21, 1984 (table 3).

Results of base-flow measurements made along Mud Creek during August 1978-September 1984 are illustrated in figure 5. The measurements show substantial inflows from creeks in Boardinghouse, Eccles, and Winter Quarters Canyons.

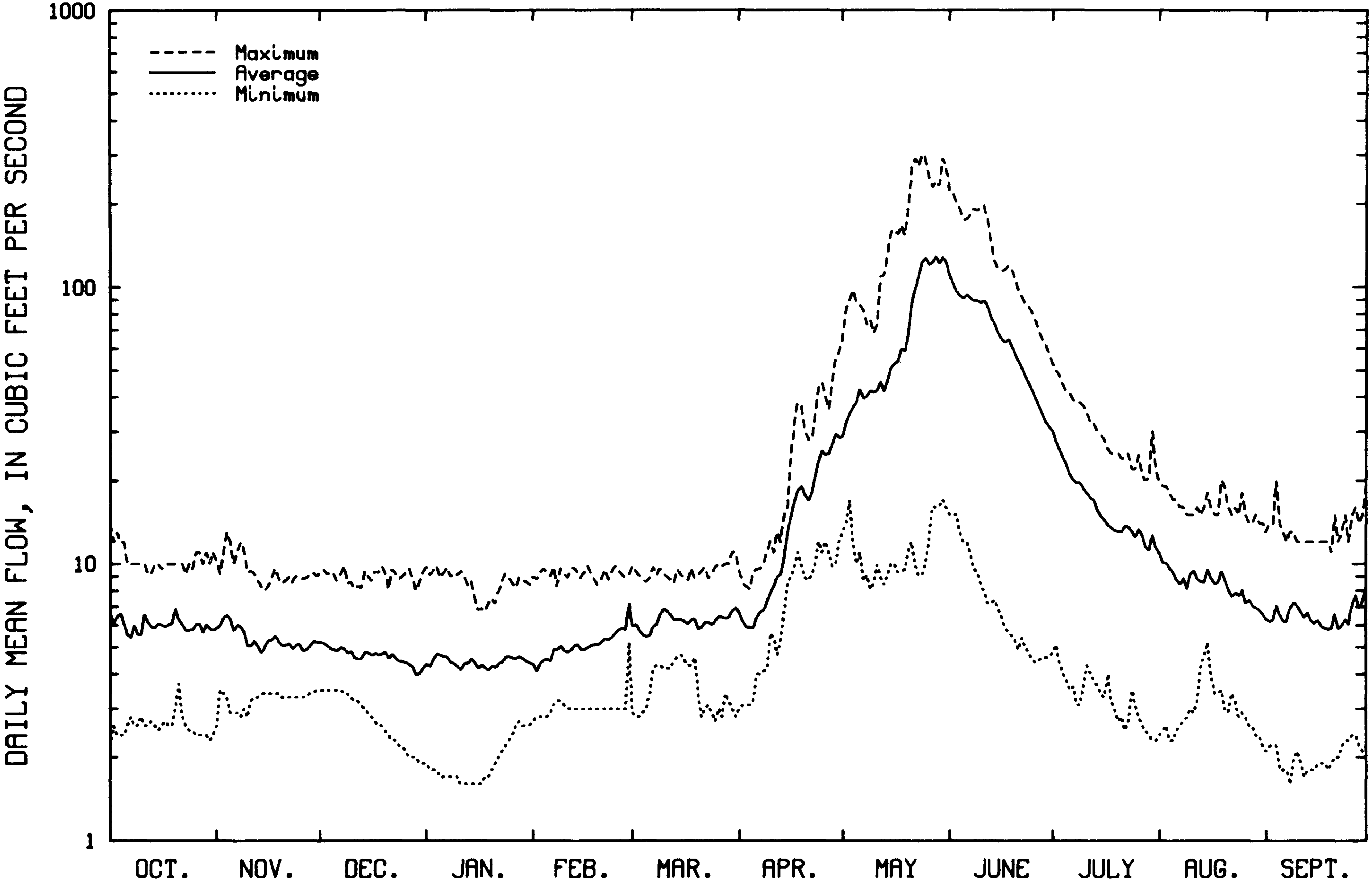

Figure 4.—Maximum, average, and minimum daily mean flow of Mud Creek at station 09310700, water years 1979-84.

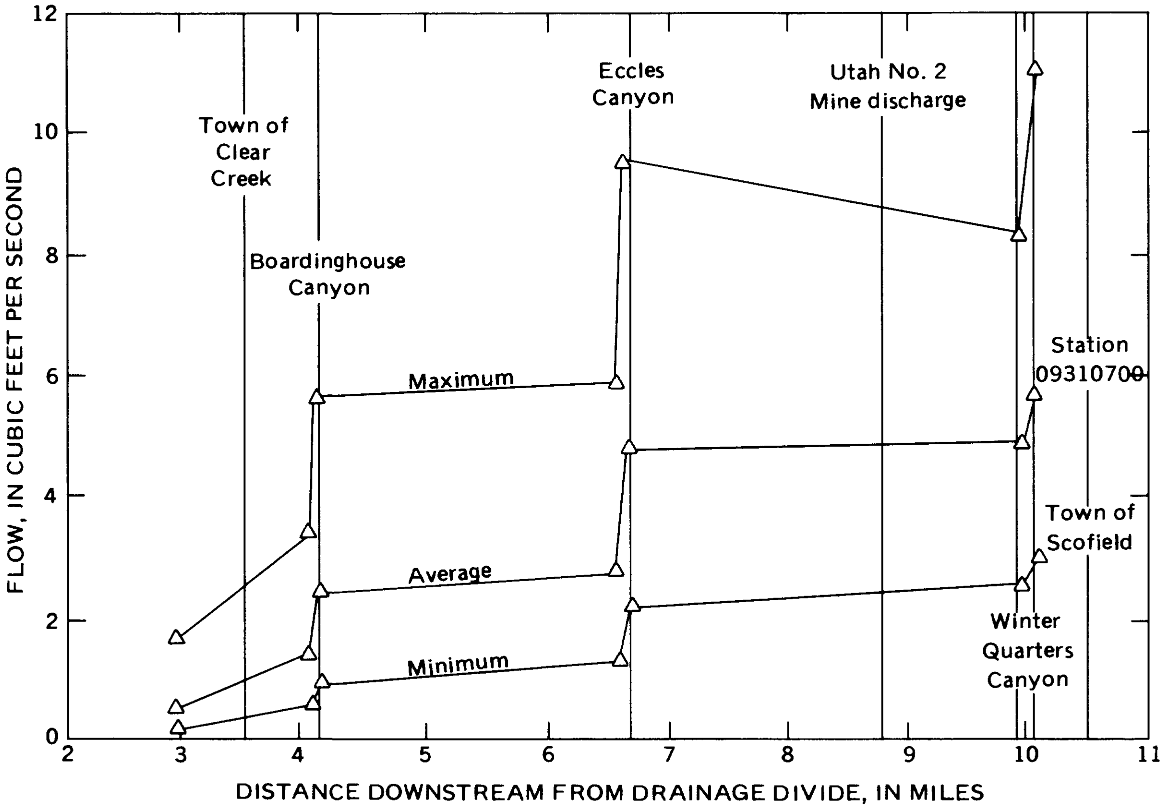

Figure 5.—Base flow of Mud Creek (based on 10 measurements made at each site from August 1978 to September 1984).

Dissolved-solids concentrations in 51 streamflow samples collected at station 09310700 during August 1978-September 1984 ranged from 170 to 390 milligrams per liter; and the mean was 315 milligrams per liter (table 5). Dominant ions found in the samples were calcium, magnesium, and bicarbonate. Of the trace elements that were analyzed, cadmium and manganese were found in concentrations that exceed the criteria established by the U.S. Environmental Protection Agency (1976) for drinking-water supplies. The maximum concentration of cadmium and manganese were 53 and 70 micrograms per liter, and these exceeded the criteria of 10 and 50 micrograms per liter for those elements. The phenol concentration in some samples exceeded the criterion of 1 microgram per liter (U.S. Environmental Protection Agency, 1976, p. 182).

Suspended-sediment concentrations in 137 streamflow samples collected at station 09310700 ranged from 14 milligrams per liter on January 13, 1981, to 1,690 milligrams per liter on May 1, 1980. The largest suspended-sediment loads are during May and June when suspended-sediment concentrations are large, and the snowmelt runoff produces the greatest sustained streamflow. Larger concentrations and loads, however, could occur in runoff from rare, intense thunderstorms. Instantaneous suspended-sediment loads determined from the suspended-sediment samples collected at station 09310700 are as follows:

Water year	Suspended-sediment load (tons/day)	
	Minimum	Maximum
1979	0.37	147
1980	.85	554
1981	.13	11
1983	(1)1.4	(1)12,700
1984	(1).70	(1)1,420

(1)Determined from additional samples collected for another project.

Benthic invertebrates were sampled at station 09310700 four times during the 1979-80 water years, and phytoplankton were sampled at the same site during the 1981 water year. The benthic invertebrates had good diversity as noted by Lines and Plantz (1981, p. 11) indicating an apparently unpolluted stream-bottom environment. The phytoplankton (five samples) had fairly uniform distribution of green algae (U.S. Geological Survey, 1982, p. 235). Some blue-green algae was found in all five phytoplankton samples.

Beaver Creek

Beaver Creek originates on the Wasatch Plateau at an altitude of about 9,200 feet, and it descends about 2,100 feet to its confluence with the Price River at about 7,100 feet. The creek originates on the coal-bearing Blackhawk Formation and flows over progressively younger geologic formations to its mouth, where it is on the Flagstaff Limestone. The Gordon Creek No. 2 Mine (pl. 1) extends into the upper Beaver Creek basin. That mine was in operation during the complete monitoring period.

Table 5.—Summary of chemical analyses of streamflow in Mud Creek at station 09310700, water years 1979–84

[< indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	59	19.6	1.6-245
Water temperature (degrees Celsius)	58	8.1	.0-23.0
Specific conductance (microsiemens per centimeter at 25° Celsius)	59	515	255-650
pH (units)	52	--	7.6-8.6
Sodium-adsorption ratio	54	.17	.0-.4
Milligrams per liter			
Dissolved solids, sum of constituents	51	315	170-390
Oxygen, dissolved (O_2)	49	9.2	7.0-11.1
Carbon dioxide, dissolved (CO_2)	39	2.6	1.1-6.7
Alkalinity ($CaCO_3$)[1]	47	198	139-350
Bicarbonate (HCO_3)[1]	37	279	170-360
Carbonate (CO_3)[1]	38	1.6	.0-16
Nitrogen, dissolved (N)	20	.82	.29-2.2
Nitrogen, organic dissolved (N)	15	.75	.05-1.2
Nitrogen, ammonia dissolved (N)	22	--	<.01-.140
Nitrogen, nitrite dissolved (N)	15	--	<.014
Nitrogen, nitrate dissolved (N)	15	--	<.05-.66
Nitrogen, nitrite + nitrate dissolved (N)	33	--	<.01-1.5
Phosphorus, dissolved (P)	25	--	<.01
Phosphorus, ortho phosphates dissolved (P)	23	--	<.001
Carbon, organic dissolved (C)	16	6.8	1.9-38
Hardness, (as $CaCO_3$)	53	275	130-360
Hardness, (as noncarbonate, $CaCO_3$)	42	44.0	.0-77
Calcium, dissolved (Ca)	54	69.0	41-89
Magnesium, dissolved (Mg)	54	22.8	7.0-30
Sodium, dissolved (Na)	54	6.4	2.6-15
Potassium, dissolved (K)	49	2.5	1.2-7.5
Chloride, dissolved (Cl)	54	9.4	2.4-24
Sulfate, dissolved (SO_4)	57	45.7	18.0-82
Fluoride, dissolved (F)	31	.20	.10-.60
Silica, dissolved (SiO_2)	49	5.0	4.9-8.0

Table 5.—Summary of chemical analyses of streamflow in Mud Creek at station 09310700, water years 1979-84—Continued

	Properties and constituents	No. of analyses	Mean	Minimum-maximum
Milligrams per liter	Arsenic, dissolved (As)	22	—	<1-2
	Barium, dissolved (Ba)	5	—	<100-100
	Boron, dissolved (B)	32	—	<10-180
	Cadmium, dissolved (Cd)	13	—	<1-53
	Chromium, dissolved (Cr)	18	—	<20
	Copper, dissolved (Cu)	13	—	<10
	Iron, dissolved (Fe)	39	—	<10-210
	Lead, dissolved (Pb)	18	—	<1-30
	Lithium, dissolved (Li)	13	—	<10-20
	Manganese, dissolved (Mn)	21	59	10-70
	Mercury, dissolved (Hg)	10	—	<.1
	Nickel, dissolved (Ni)	6	—	<1-2
	Selenium, dissolved (Se)	21	—	<1-1
	Strontium, dissolved (Sr)	13	201	110-260
	Zinc, dissolved (Zn)	22	—	<3-35
	Phenols	16	—	<1-7

[1]Fixed-end-point determined by titration in the field.

The monitoring program summarized in this report for Beaver Creek was limited to only a series of base-flow measurements. The U.S. Geological Survey, however, has operated station 09312700 on the creek (pl. 1) since water year 1961 as part of a Statewide network. (See ReMillard and others, 1985, and previous reports in that series.) Average flow for water years 1961-84 was 4.58 cubic feet per second, and the mean monthly flow ranged from about 0.68 cubic feet per second in January to about 24.5 cubic feet per second in May. The maximum peak flow was 204 cubic feet per second May 27, 1973, and there was no flow on a number of days.

Maximum, minimum, and average base flows in Beaver Creek as measured during August 1978-August 1981 (generally two sets of measurements per year) are related to geology in figure 6. The average base flow increased about 0.3 cubic feet per second per mile where the stream crosses the Blackhawk Formation and Castlegate Sandstone, and decreased about 0.1 cubic feet per second per mile where the stream crosses the Price River Formation and younger rocks.

During 1969-70, some water-quality data were collected at station 09312700. Those data are summarized by Mundorff (1972, table 4). The data show that dissolved-solids concentrations in the streamflow ranged from 203 to 271 milligrams per liter, and that calcium and bicarbonate were the dominant dissolved ions.

Willow Creek

Willow Creek originates on the Green River Formation of Tertiary age at an altitude of about 9,200 feet on the West Tavaputs Plateau. The stream descends more than 3,000 feet through progressively older geologic formations to its confluence with the Price River at about 6,000 feet. At the confluence, both streams are on the coal-bearing Blackhawk Formation. Coal in the Blackhawk was being mined at the Braztah Mines (pl. 1) in the lower Willow Creek drainage during the monitoring period on Willow Creek.

Station 09312900 (pl. 1, table 1) was operated on lower Willow Creek during water years 1980-81. Data collected at that station supplement the long-term record at upstream station 09312800 (pl. 1) which is part of the U.S. Geological Survey's statewide network (ReMillard and others, 1985).

The annual mean flow of Willow Creek at station 09312900 was 17.3 cubic feet per second in water year 1980 and 4.58 cubic feet per second in water year 1981 (table 3). The maximum, minimum, and average daily mean flow recorded at the station during the 2 water years are shown in figure 7, which shows most of the annual flow in Willow Creek is from April to July. The source of the flow is chiefly snowmelt from the West Tavaputs Plateau. The short-term increases in flow during August and September reflect runoff from thunderstorms. The maximum peak flow recorded at the station was 210 cubic feet per second on May 23, 1980 (table 3).

During August 1978-August 1981, seven sets of base-flow measurements were made along Willow Creek downstream from station 09312800. Those measurements are related to geology in figure 8. They show a slight gain in flow where the stream crosses the North Horn Formation but virtually no change in flow where it crosses older rocks, including the coal-bearing Blackhawk Formation.

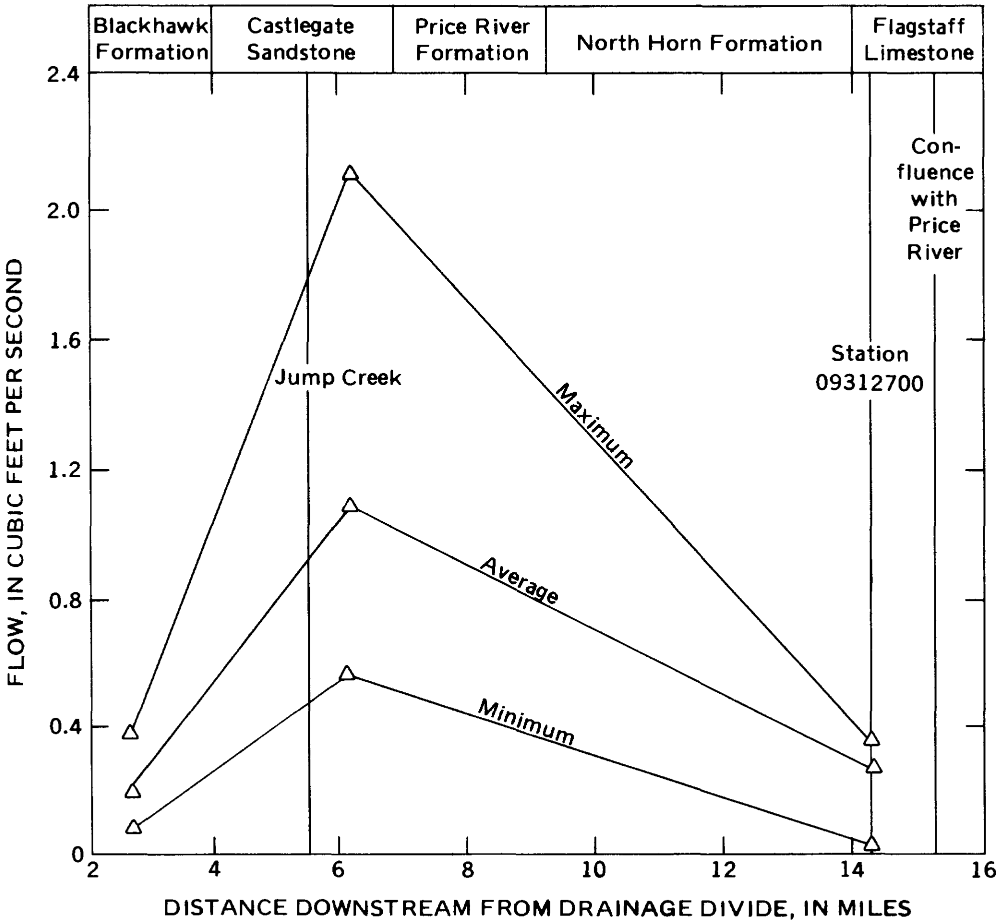

Figure 6.—Base flow of Beaver Creek as related to geology (based on 7 measurements made at each site from August 1978 to August 1981).

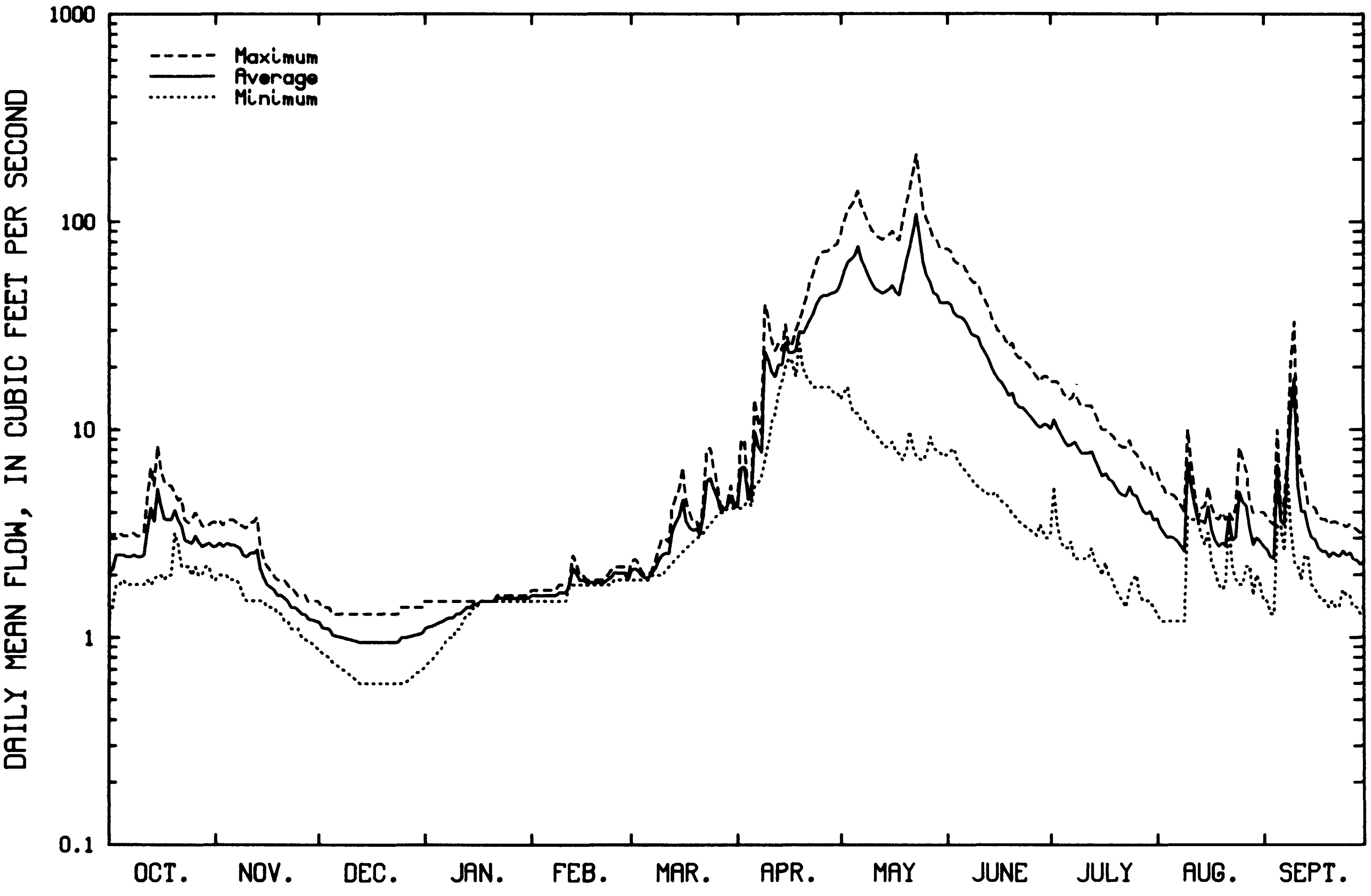

Figure 7.—Maximum, average, and minimum daily mean flow of Willow Creek at station 09312900, water years 1980-81.

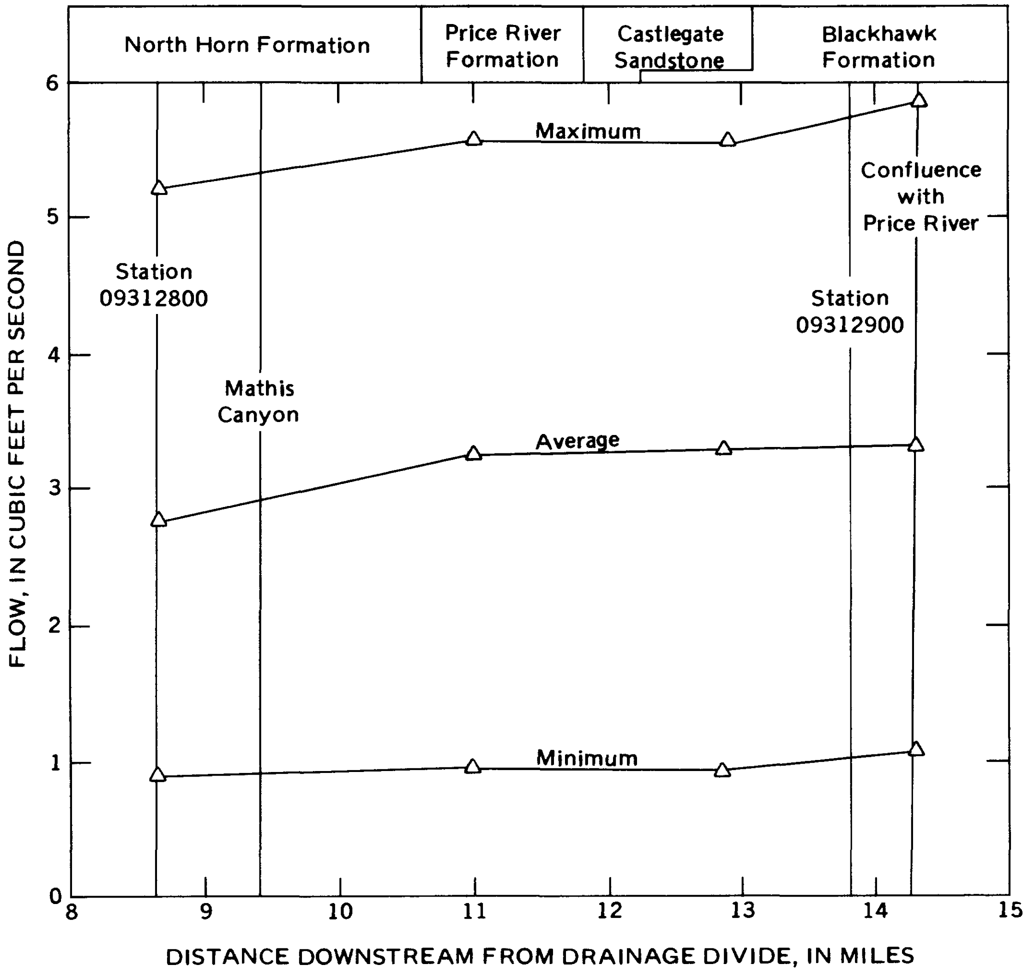

Figure 8.—Base flow of Willow Creek as related to geology (based on 7 measurements made at each site from August 1978 to August 1981).

Chemical analyses of 24 streamflow samples collected at station 09312900 during the 1980 and 1981 water years are summarized in table 6. Dissolved-solids concentrations in the samples ranged from 350 to 810 milligrams per liter, with a mean of 591 milligrams per liter. Magnesium and bicarbonate were respectively the dominant cation and anion in most of the samples regardless of the total dissolved-solids concentrations. Although strontium was found in concentrations as large as 1,100 micrograms per liter, no other trace element that was analyzed was found in concentrations that exceed the criteria established by the U.S. Environmental Protection Agency (1976) for drinking-water supplies. Analysis of eight samples for phenol concentration showed that all equaled or exceeded the U.S. Environmental Protection Agency (1976, p. 183) criterioin of 1 microgram per liter.

Sediment data also were collected at station 09312900 during the 1980 and 1981 water years. Suspended-sediment concentrations in 20 samples ranged from 2 milligrams per liter on December 6, 1980, to 4,820 milligrams per liter on April 15, 1981. The calculated instantaneous suspended-sediment loads ranged from 0.02 to 902 tons per day in water year 1980 and from 0.01 to 547 tons per day in water year 1981. Analyses of stream-bottom sediments at station 09312900 indicate that those sediments consist of as much as 2.3 percent coal. The most likely source of the coal is upstream coal storage or mine spoils on the land surface.

Two benthic invertebrate samples were collected during water year 1980 and five phytoplankton samples were collected during water year 1981 at station 09312900. The benthic invertebrates had fairly good diversity (U.S. Geological Survey, 1981, p. 248), indicating an apparently unpolluted stream-bottom environment. The phytoplankton showed considerable variation in the samples (U.S. Geological Survey, 1982, p. 246).

Price River

Flow of the Price River upstream from station 09313000 (pl. 1, table 1) is regulated at Scofield Reservoir. Between station 09313000 and Scofield Reservoir, the Price River receives significant inflows from the White River and Beaver and Willow Creeks. The Braztah Mining Co. was mining coal in the general area of station 09313000 during water years 1980-81 when the station was being monitored.

Prior to the monitoring program, station 09313000 was operated for many years as part of the U.S. Geological Survey's statewide network. The annual average flow at the station during 37 years of record, including the monitoring period, was 112 cubic feet per second (table 3). The maximum, minimum, and average daily mean flow at the station during those 37 years, which is shown in figure 9, indicates a relatively uniform year-round flow that reflects regulation at Scofield Reservoir. The short-term peaks of the maximum daily mean in August and September probably are due to thunderstorms over the drainage basins of one or more of the three main tributaries to the Price River. The maximum peak flow was 9,340 cubic feet per second on September 13, 1940 (table 3). This flow, which resulted from thunderstorm activity over the drainage basins of the three above-mentioned tributaries, caused considerable flood damage in the cities of Price and Helper (Butler and Marsell, 1972, p. 53).

Table 6.--Summary of chemical analyses of streamflow in Willow Creek at station 09312900, water years 1980-81

[< indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	25	12.1	0.35-173
Water temperature (degrees Celsius)	25	10.0	.0-27.0
Specific conductance (microsiemens per centimeter at 25° Celsius)	25	920	450-1,280
pH (units)	25	--	8.1-8.8
Sodium-adsorption ratio	25	1.8	.9-2.0
Milligrams per liter			
Dissolved solids, sum of constituents	24	591	350-810
Oxygen, dissolved (O_2)	25	9.3	6.4-12.0
Carbon dioxide, dissolved (CO_2)	24	1.9	.7-4.7
Alkalinity $(CaCO_3)$	24	284	210-350
Bicarbonate (HCO_3)[1]	24	331	230-420
Carbonate (CO_3)[1]	24	7.3	.0-16
Nitrogen, dissolved (N)	8	.45	.15-.74
Nitrogen, organic dissolved (N)	4	.37	.11-.63
Nitrogen, ammonia dissolved (N)	4	--	<.01-.030
Nitrogen, nitrite dissolved (N)	4	--	.01
Nitrogen, nitrate dissolved (N)	4	--	<.05-.06
Nitrogen, nitrite + nitrate dissolved (N)	8	--	<.01-.27
Phosphorus, dissolved (P)	4	--	<.01-.240
Phosphorus, ortho phosphates dissolved (P)	4	--	.001-.010
Carbon, organic dissolved (C)	8	6.2	1.5-14
Hardness, (as $CaCO_3$)	25	342	180-500
Hardness, (as noncarbonate, $CaCO_3$)	24	65	.0-150
Calcium, dissolved (Ca)	25	56	32.0-82
Magnesium, dissolved (Mg)	25	49	20-72
Sodium, dissolved (Na)	25	77	30-100
Potassium, dissolved (K)	25	2.7	1.7-3.6
Chloride, dissolved (Cl)	25	26.1	9.8-45
Sulfate, dissolved (SO_4)	25	194	70-300
Fluoride, dissolved (F)	17	.26	.20-0.50
Silica, dissolved (SiO_2)	25	12.2	6.8-15

Table 6.--Summary of chemical analyses of streamflow in Willow Creek at station 09312900, water years 1980-81--Continued

Milligrams per liter

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Arsenic, dissolved (As)	6	2.2	2.0-3.0
Barium, dissolved (Ba)	12	150	100-200
Boron, dissolved (B)	17	97	60-180
Cadmium, dissolved (Cd)	2	--	<1-1
Chromium, dissolved (Cr)	5	--	<10-10
Copper, dissolved (Cu)	2	2.5	2-3
Iron, dissolved (Fe)	17	--	<10-80
Lead, dissolved (Pb)	6	--	<1-2
Lithium, dissolved (Li)	6	28	20-40
Manganese, dissolved (Mn)	17	12.2	2-30
Mercury, dissolved (Hg)	2	--	<.1
Nickel, dissolved (Ni)	2	--	<1
Selenium, dissolved (Se)	6	1.7	1.0-3.0
Strontium, dissolved (Sr)	6	717	350-1,100
Zinc, dissolved (Zn)	6	4.2	3.0-7.0
Phenols	8	7.2	1.0-33

[1]Fixed-end-point determined by titration in the field.

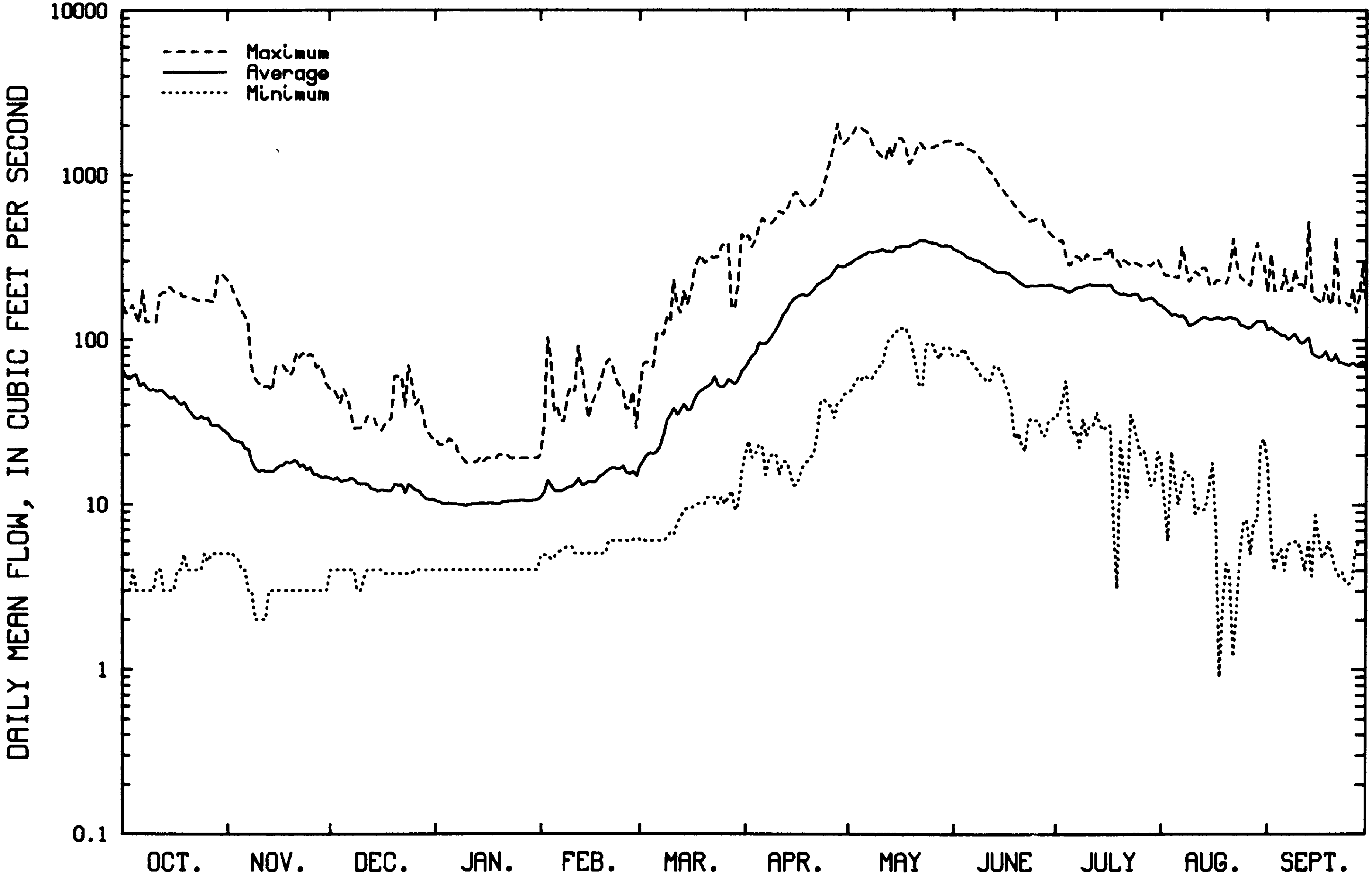

Figure 9.—Maximum, average, and minimum daily mean flow of the Price River at station 09313000, water years 1935-70, 1980-81.

Dissolved-solids concentrations in 24 streamflow samples collected from the Price River at station 09313000 during October 1979-September 1981 ranged from 200 to 580 milligrams per liter with a mean of 367 milligrams per liter (table 7). Calcium and magnesium were the dominant dissolved cations, and bicarbonate was the dominant dissolved anion. Concentrations of all trace elements that were analyzed were smaller than the criteria established by the U.S. Environmental Protection Agency (1976) for drinking-water supplies. The phenol concentration in some samples, however, exceeded the criterion of 1 microgram per liter.

Concentrations of suspended sediment in 21 streamflow samples collected at station 09313000 ranged from 58 to 1,520 milligrams per liter during water year 1980 and from 21 to 4,270 milligrams per liter during water year 1981. Instantaneous suspended-sediment loads ranged from 2.7 to 3,770 tons per day during water year 1980 and from 0.59 to 1,090 tons per day during water year 1981. Coal was as much as 8 percent of the stream-bottom sediments sampled at the station.

Two samples of benthic invertebrates collected at station 09313000 during the 1980 water year had good diversity (U.S. Geological Survey, 1981, p. 253), indicating an apparently unpolluted stream bottom at the station. Five samples of phytoplankton collected during water year 1981 showed a uniform distribution of green algae with good diversity (U.S. Geological Survey, 1982, p. 253).

Spring Canyon Creek

Spring Canyon creek orginates on the Wasatch Plateau at an altitude of about 9,800 feet. It descends about 4,000 feet to its confluence with the Price River at about 5,800 feet. All the Cretaceous formations shown on figure 1 are exposed in the canyon, and station 09313040 is located where the creek flows on the Mancos Shale at an altitude of 6,110 feet.

Coal mining started in Spring Canyon during the late 1800's and continued intermittently to the present (1985). During the monitoring period of water years 1979-81 at station 09313040, coal was actively mined at the Braztah Mines (pl. 1) with portals in Spring Canyon. Most of the water produced by the mines is consumed in the mining operations; however, a small, but unknown quantity was intermittently discharged to Spring Canyon creek.

Most of the flow in Spring Canyon creek originates in seeps or springs. The annual mean flow at station 09313040 during the 3 years of record ranged from 0.12 cubic feet per second during water year 1979 to 0.41 cubic feet per second during water year 1981 (table 3). The flow varies considerably, and the short-term increases in flow during June-November shown in figure 10 probably resulted from thunderstorms. The maximum peak flow recorded, which was 271 cubic feet per second on July 12, 1981 (table 3), resulted from a thunderstorm.

The results of base-flow measurements made in Spring Canyon creek upstream from station 09313040 are related to geology in figure 11. The marked increase in base flow beginning about 2.5 miles upstream from the station probably reflects increased spring inflow to the canyon from near the contact between the Mancos Shale and the Star Point Sandstone.

Table 7.—Summary of chemical analyses of streamflow in the Price River at station 09313000, water years, 1980–81

[< indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	25	124	6.8–918
Water temperature (degrees Celsius)	25	9.4	.0–20.0
Specific conductance (microsiemens per centimeter at 25° Celsius)	25	579	330–930
pH (units)	25	—	8.1–9.0
Sodium-absorption ratio	25	.7	.3–1.0
Milligrams per liter			
Dissolved solids, sum of constituents	24	367	200–580
Oxygen, dissolved (O_2)	25	9.8	7.5–13.1
Carbon dioxide, dissolved (CO_2)	24	1.4	.5–3.9
Alkalinity ($CaCO_3$)	24	217	140–290
Bicarbonate (HCO_3)[1]	24	250	170–400
Carbonate (CO_3)[1]	24	5.8	.0–22
Nitrogen, dissolved (N)	8	.70	.20–.94
Nitrogen, organic dissolved (N)	4	.35	.11–.52
Nitrogen, ammonia dissolved (N)	4	—	<.01–.050
Nitrogen, nitrite dissolved (N)	4	—	<.010
Nitrogen, nitrate dissolved (N)	4	—	<.05–.50
Nitrogen, nitrite + nitrate dissolved (N)	8	.27	.03–.50
Phosphorus, dissolved (P)	4	.075	.010–.270
Phosphorus, ortho phosphates dissolved (P)	4	—	<.001–.010
Carbon, organic dissolved (C)	8	7.0	2.2–15
Hardness, (as $CaCO_3$)	25	255	160–390
Hardness, (as noncarbonate, $CaCO_3$)	24	44.8	0–130
Calcium, dissolved (Ca)	25	57	36–85
Magnesium, dissolved (Mg)	25	27	16–47
Sodium, dissolved (Na)	25	27.7	7.9–56.0
Potassium, dissolved (K)	25	1.9	.9–3.2
Chloride, dissolved (Cl)	25	17.2	5.8–41.0
Sulfate, dissolved (SO_4)	25	88	28–200
Fluoride, dissolved (F)	17	.2	.1–.3
Silica, dissolved (SiO_2)	25	8.1	3.3–14.0

Table 7.—Summary of chemical analyses of streamflow in the Price River at station 09313000, water years, 1980-81—Continued

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Milligrams per liter			
Arsenic, dissolved (As)	6	1.7	1.0-3.0
Barium, dissolved (Ba)	2	—	<100-200
Boron, dissolved (B)	17	136	20-610
Cadmium, dissolved (Cd)	2	—	<1-2
Chromium, dissolved (Cr)	6	—	<10-20
Copper, dissolved (Cu)	2	3.0	2.0-4.0
Iron, dissolved (Fe)	17	—	<10-30
Lead, dissolved (Pb)	6	—	<1-5.0
Lithium, dissolved (Li)	6	—	<10-30
Manganese, dissolved (Mn)	17	11.2	3.0-30
Mercury, dissolved (Hg)	2	—	<.1
Nickel, dissolved (Ni)	2	8	2-14
Selenium, dissolved (Se)	6	—	<1-3.0
Strontium, dissolved (Sr)	6	455	300-630
Zinc, dissolved (Zn)	6	—	<3-20
Phenols	7	—	<1-10

[1]Fixed-end-point determined by titration in the field.

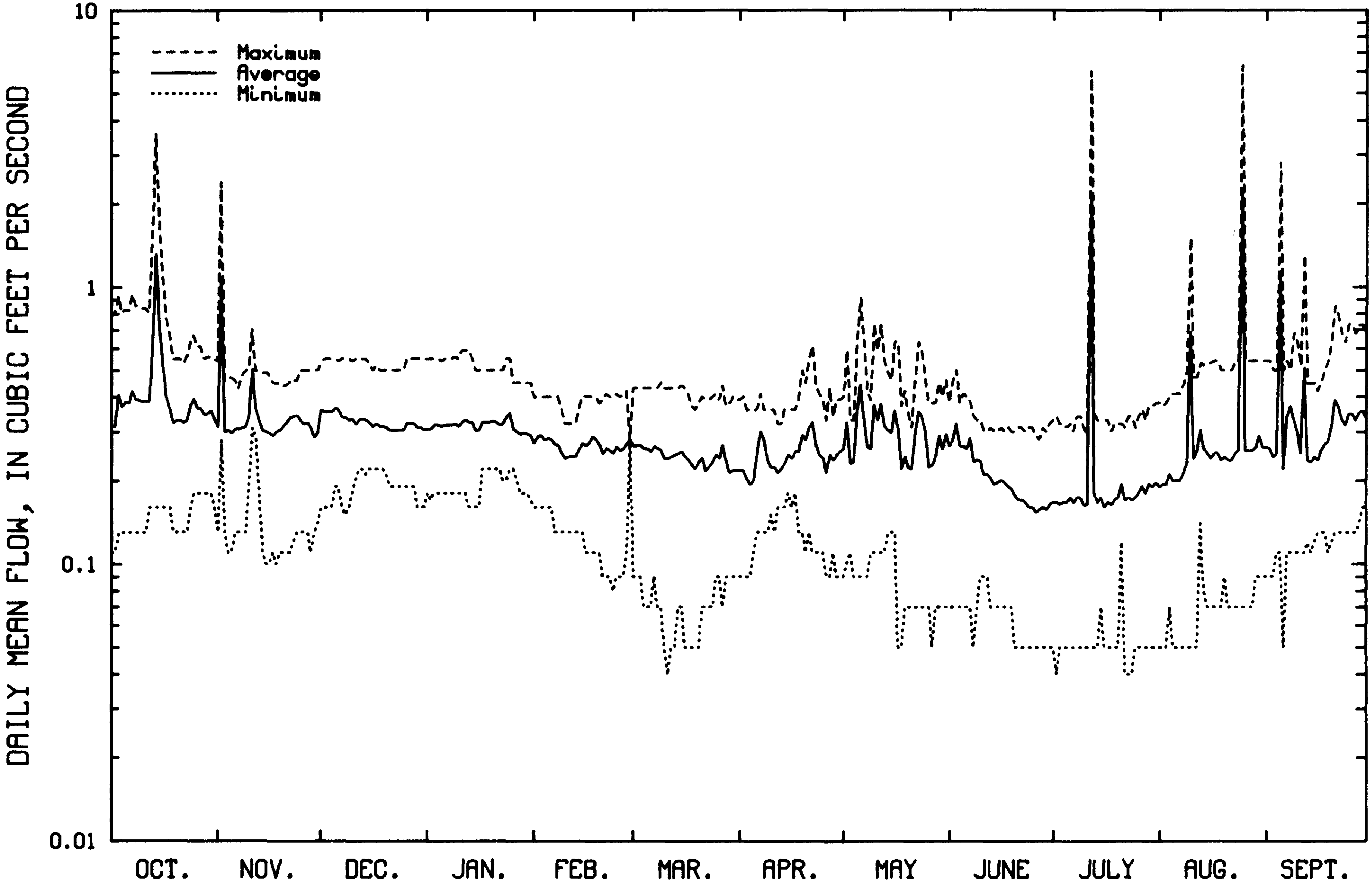

Figure 10.—Maximum, average, and minimum daily mean flow of Spring Canyon creek at station 09313040, water years 1979-81.

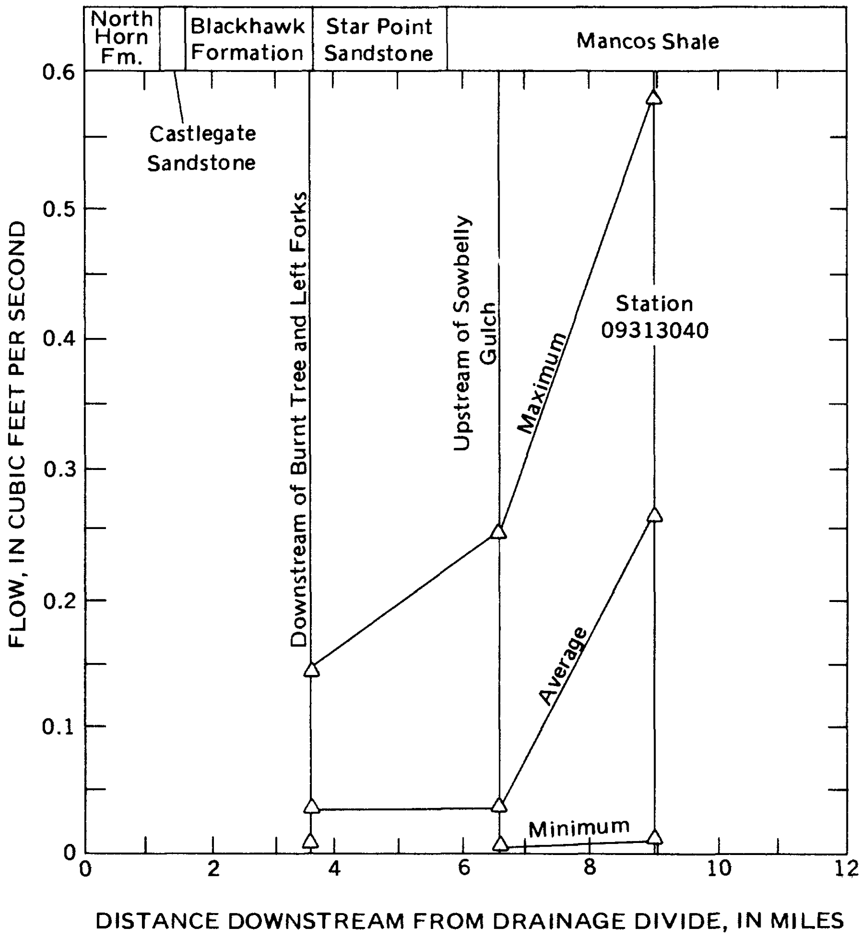

Figure 11.—Base flow of Spring Canyon creek as related to geology (based on 7 measurements made at each site from August 1978 to August 1981).

Dissolved-solids concentrations in 37 streamflow samples taken from Spring Canyon creek at station 09313040 ranged from 481 to 2,600 milligrams per liter; with a mean of 2,260 milligrams per liter (table 8). Magnesium and sulfate were the dominant cation and anion. Strontium was the dominant trace element, with concentrations as large as 1,400 micrograms per liter. Of the trace elements that were analyzed, only lead and selenium were found in concentrations that exceeded the criteria established by the U.S. Environmental Protection Agency (1976) for drinking-water supplies. Both the maximum and mean concentrations of selenium exceeded the criterion of 10 micrograms per liter, and the maximum concentration of lead exceeded the criterion of 50 micrograms per liter.

Suspended-sediment concentrations in 25 streamflow samples collected from Spring Canyon creek at station 09313040 during the 3 years of monitoring ranged from 3 milligrams per liter on December 6, 1981 to 99,800 milligrams per liter on July 12, 1981. Instantaneous suspended-sediment loads ranged from 0.05 to 0.07 tons per day during water year 1979, 0.01 to 0.43 tons per day in water year 1980, and from less than 0.01 to 10,200 tons per day in water year 1981. No determinations were made of the composition of suspended sediment in samples collected during the monitoring period. On August 29, 1969, however, Spring Canyon creek, while flowing at a rate of 0.6 cubic feet per second, had a suspended-sediment concentration of 2,260 milligrams per liter and about 90 percent of the suspended sediment was coal (Mundorff, 1972, p. 37). Most likely sources of the coal particles are coal spills, mine spoils, and coal-loading facilities associated with the earlier mines in the canyon.

Four samples of benthic invertebrates were collected at station 09313040 during the 1980 water year showed only fair diversity (U.S. Geological Survey, 1981, p. 258). Lines and Plantz (1981, p. 17) had a similar report for water year 1979. Five samples of phytoplankton during the 1981 water year showed a fairly uniform dispersion of green algae. Blue-green algae, however, were also well represented in the samples (U.S. Geological Survey, 1982, p. 260).

North Fork of Gordon Creek

The North Fork of Gordon Creek originates on the coal-bearing Blackhawk Formation at an altitude of about 9,600 feet. The stream has cut a canyon through the Blackhawk and the older geologic formations shown in figure 1. It apparently receives most of its base flow from Coal Canyon (Lines and Plantz, 1981, p. 17).

Most of the Gordon Creek No. 2 Mine is in the North Fork of Gordon Creek drainage. The mine was in operation during the complete monitoring period. According to Lines and Plantz (1981, p. 17) an unknown quantity of water which is intermittently discharged from the mine, has a dissolved-solids concentration of about 800 milligrams per liter. This is about 35 percent of the largest dissolved-solids concentration found in Gordon Creek near where it discharges to the Price River (Mundorff, 1972, table 4).

Table 8.—Summary of chemical analyses of streamflow in Spring Canyon creek at station 09313040, water years 1979-81

[< indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	37	1.4	0.05-38.0
Water temperature (degrees Celsius)	37	11.4	4.0-26.0
Specific conductance (microsiemens per centimeter at 25° Celsius)	37	2,890	770-3,200
pH (units)	37	—	7.8-8.4
Sodium-adsorption ratio	37	1.6	.3-5.5
Milligrams per liter			
Dissolved solids, sum of constituents	37	2,260	481-2,600
Oxygen, dissolved (O_2)	37	9.0	7.0-11.2
Carbon dioxide, dissolved (CO_2)	36	4.9	1.9-7.7
Alkalinity ($CaCO_3$)	36	382	100-430
Bicarbonate (HCO_3)[1]	36	468	120-520
Carbonate (CO_3)[1]	36	—	.0-2
Nitrogen, dissolved (N)	7	7.1	3.1-8.5
Nitrogen, organic dissolved (N)	8	.71	.40-1.4
Nitrogen, ammonia dissolved (N)	8	—	<.01-.190
Nitrogen, nitrite dissolved (N)	3	—	<.01-.020
Nitrogen, nitrate dissolved (N)	7	5.9	5.0-6.8
Nitrogen, nitrite + nitrate dissolved (N)	12	6.0	1.5-7.8
Phosphorus, dissolved (P)	4	—	<.01-.220
Phosphorus, ortho phosphates dissolved (P)	8	—	<.001-.030
Carbon, organic dissolved (C)	8	8.7	2.6-28
Hardness, (as $CaCO_3$)	37	1,440	370-2,100
Hardness, (as noncarbonate, $CaCO_3$)	36	1,190	270-1,700
Calcium, dissolved (Ca)	37	202	79-230
Magnesium, dissolved (Mg)	37	258	42-380
Sodium, dissolved (Na)	37	143	15-360
Potassium, dissolved (K)	37	17.5	1.7-21
Chloride, dissolved (Cl)	37	84.9	36-120
Sulfate, dissolved (SO_4)	37	1,300	200-1,500
Fluoride, dissolved (F)	21	.4	.3-.5
Silica, dissolved (SiO_2)	37	11.4	5.0-16

Table 8.—Summary of chemical analyses of streamflow in Spring Canyon creek at station 09313040, water years 1979-81—Continued

Milligrams per liter

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Arsenic, dissolved (As)	11	--	<1-3
Barium, dissolved (Ba)	2	150	100-200
Boron, dissolved (B)	21	--	<10-700
Cadmium, dissolved (Cd)	3	--	<1-1
Chromium, dissolved (Cr)	7	--	<10-30
Copper, dissolved (Cu)	3	5	2-10
Iron, dissolved (Fe)	21	34	10-60
Lead, dissolved (Pb)	11	--	<1-81
Lithium, dissolved (Li)	10	173	150-190
Manganese, dissolved (Mn)	21	23	10-50
Mercury, dissolved (Hg)	3	--	<1-1
Nickel, dissolved (Ni)	3	2.7	1-6
Selenium, dissolved (Se)	11	15	3-21
Strontium, dissolved (Sr)	10	1,200	1,000-1,400
Zinc, dissolved (Zn)	11	20	10-40
Phenols	8	--	<1-14

[1]Fixed-end-point determined by titration in the field.

Hydrologic monitoring on the North Fork of Gordon Creek was limited to seven sets of base-flow measurements during August 1978-August 1981. The results of those measurements are related to geology in figure 12, and they indicate that the base flow increases significantly directly downstream from the confluence of Coal Canyon and the North Fork of Gordon Creek.

Coal Creek

Coal Creek originates near the crest of the Book Cliffs at an altitude of about 9,000 feet. The headwater area is underlain by the Green River and Wasatch Formations of Tertiary age. The stream has cut a deep, narrow canyon into the Cretaceous formations shown in figure 1. The channel is steep to the base of the Book Cliffs, thereupon the stream meanders over a gently sloping plain on the Mancos Shale to its confluence with the Price River. Station 09313965 (pl. 1, table 1) is on the Star Point Sandstone at 6,370 feet.

There was no active coal mining in the Coal Creek basin during the monitoring period. There are, however, several hundred acres of leased Federal coal (pl. 1) and two abandoned mines in the basin.

Seasonal records were collected at station 09313965 during water years 1979-81 (table 1). The maximum, minimum, and average daily mean flow recorded at the station is shown in figure 13. Most of the recorded flow is from late May to early June, and it originates primarily from snowmelt in the higher altitudes of the basin. The maximum peak flow recorded at the station during the 3 water years of seasonal record, which was 458 cubic feet per second on August 13, 1979, resulted from an intense thunderstorm.

Base-flow measurements in Coal Creek upstream from station 09313965 are related to geology in figure 14. The average and maximum base-flow values indicate that the stream gains flow from both the Blackhawk Formation and the Star Point Sandstone. The minimum values, however, indicate that the stream loses flow near the Blackhawk-Star Point contact.

The dissolved-solids concentrations in 22 streamflow samples collected from Coal Creek at station 09313965 during the 1979-81 water years ranged from 480 to 810 milligrams per liter, with a mean of 605 milligrams per liter (table 9). Magnesium and sodium were generally the dominant cations, while bicarbonate and sulfate were generally the dominant anions. Of the trace elements that were analyzed, manganese and mercury were found in concentrations that exceed the criteria established by the U.S. Environmental Protection Agency (1976) for drinking-water supplies. The maximum concentrations of manganese and mercury were 80 and 5 micrograms per liter, compared to criteria of 50 and 2 micrograms per liter. The maximum phenol concentration was 35 micrograms per liter, compared to a criterion of 1 microgram per liter.

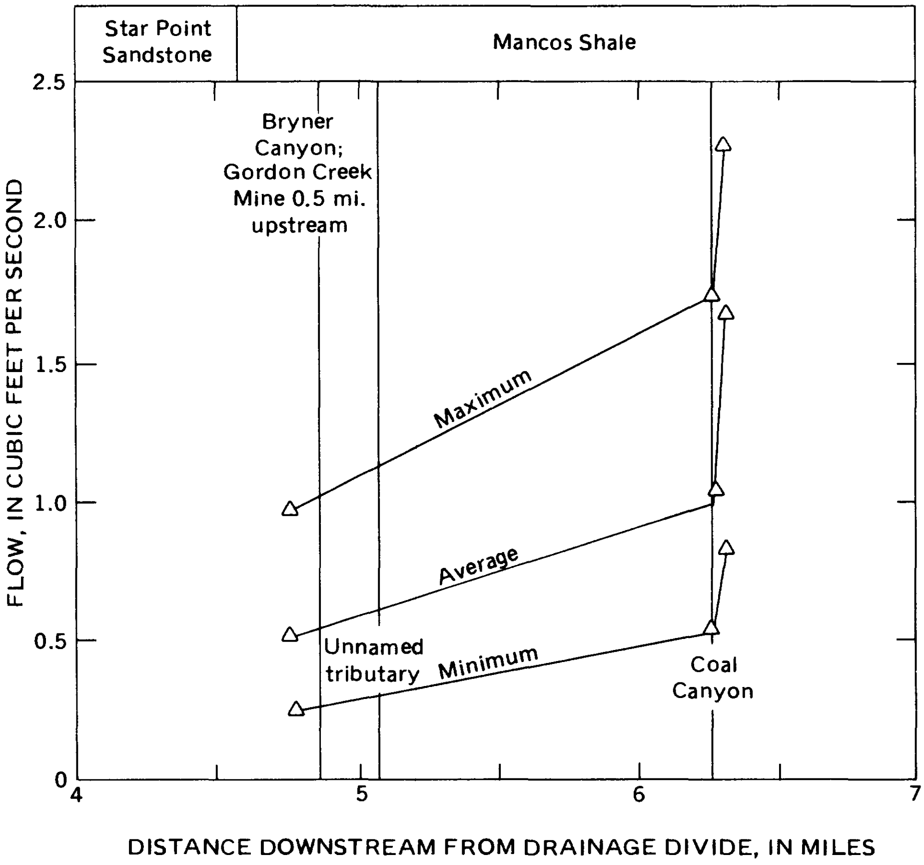

Figure 12.—Base flow of the North Fork of Gordon Creek as related to geology (based on 7 measurements made at each site from August 1978 to August 1981).

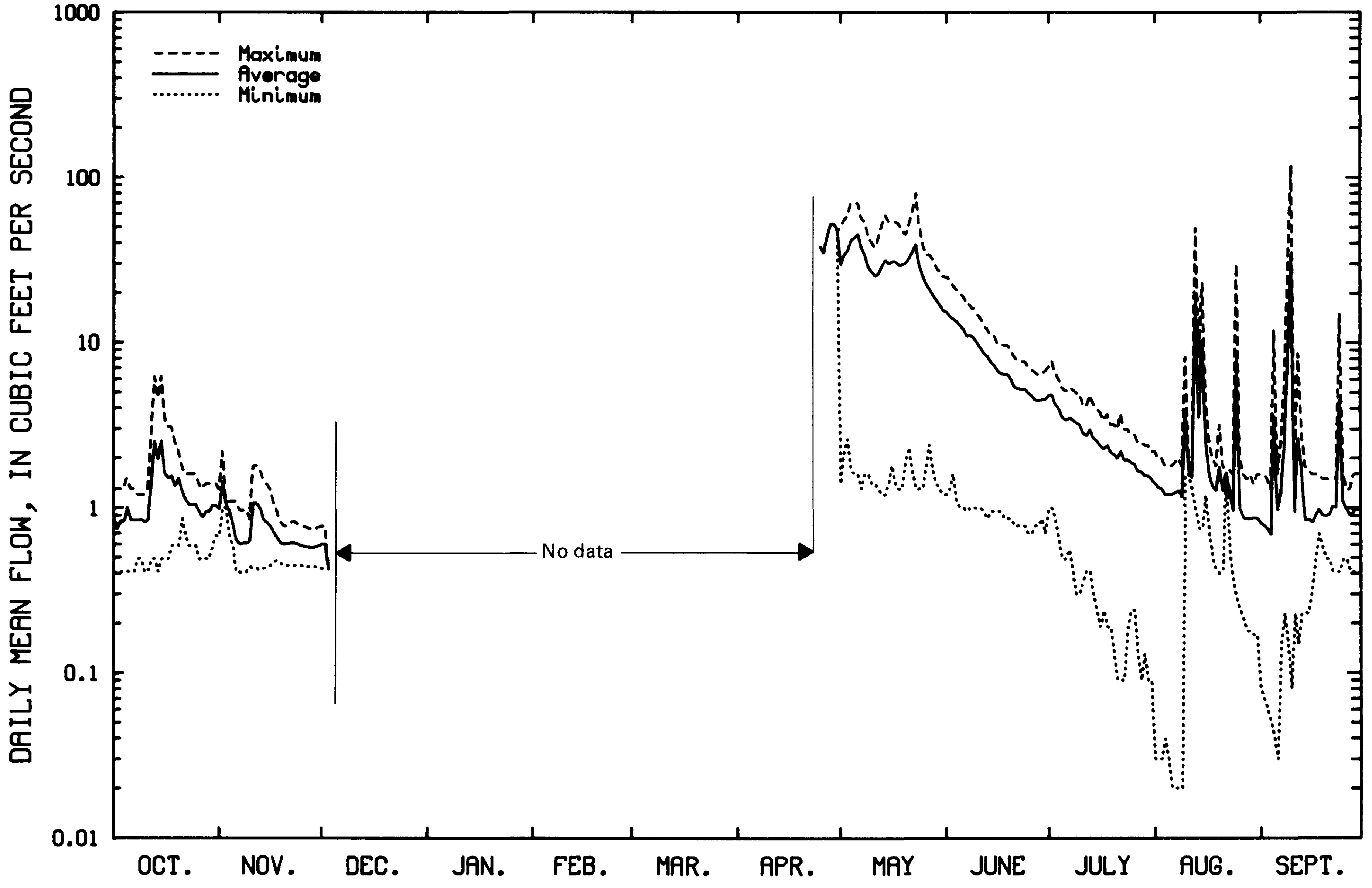

Figure 13.—Maximum, average, and minimum daily mean flow of Coal Creek at station 09313965, seasonal record for water years 1979-81.

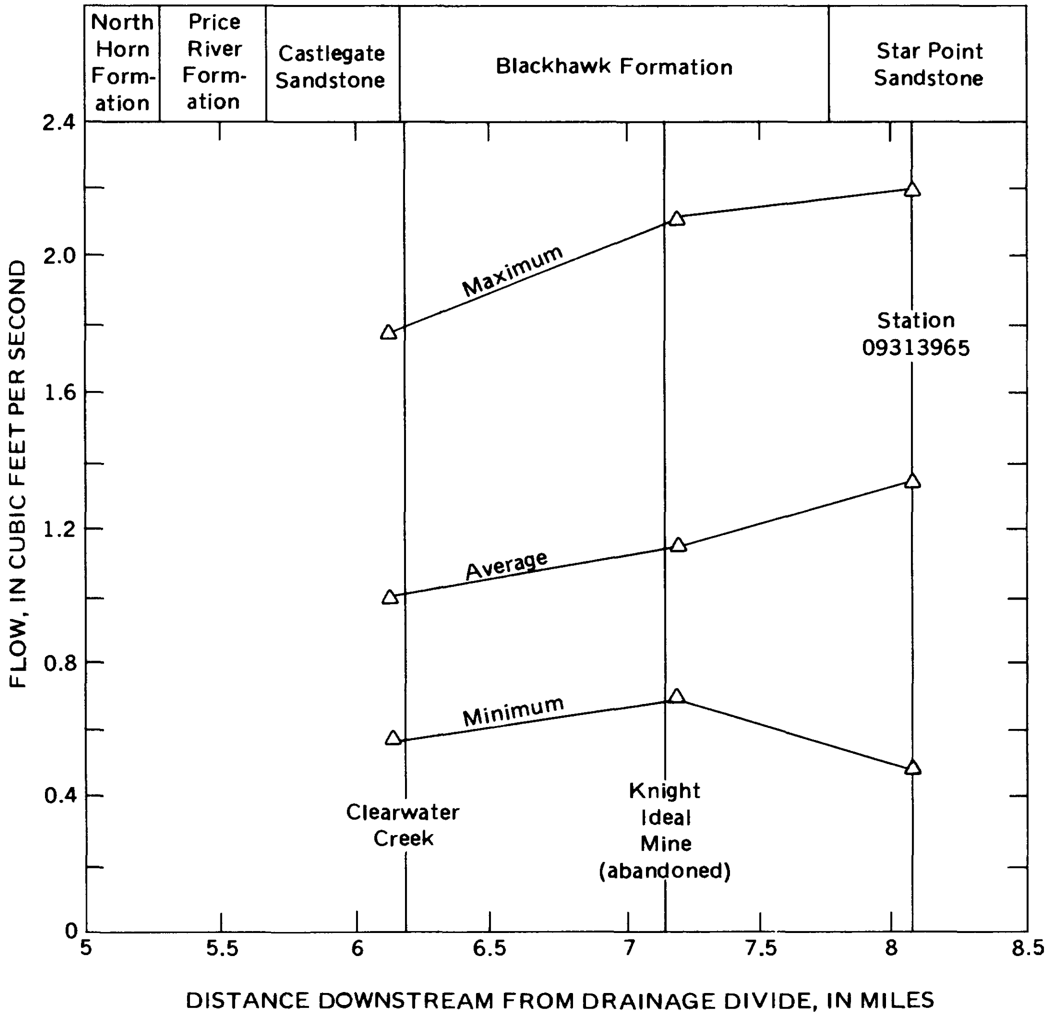

Figure 14.—Base flow of Coal Creek as related to geology (based on 7 measurements made at each site from August 1978 to August 1981).

Table 9.—Summary of chemical analyses of streamflow in Coal Creek at station 09313965, water years 1979–81

[< indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum–maximum
Streamflow (cubic feet per second)	23	3.1	0.39–0.33
Water temperature (degrees Celsius)	22	12.0	.0–22.5
Specific conductance (microsiemens per centimeter at 25° Celsius)	23	927	760–1,220
pH (units)	23	--	8.3–9.0
Sodium-adsorption ratio	23	1.8	.5–3.0
Milligrams per liter			
Dissolved solids, sum of constituents	22	605	480–810
Oxygen, dissolved (O_2)	23	8.8	6.8–11.6
Carbon dioxide, dissolved (CO_2)	22	1.5	.5–3.1
Alkalinity ($CaCO_3$)	22	317	260–400
Bicarbonate (HCO_3)[1]	21	360	310–470
Carbonate (CO_3)[1]	21	17.1	0–41
Nitrogen, dissolved (N)	7	.76	.32–1.90
Nitrogen, organic dissolved (N)	6	4.26	.19–24.0
Nitrogen, ammonia dissolved (N)	6	--	.070
Nitrogen, nitrite dissolved (N)	6	--	<.010
Nitrogen, nitrate dissolved (N)	6	.16	.07–25
Nitrogen, nitrite + nitrate dissolved (N)	9	.17	.04–.29
Phosphorus, dissolved (P)	3	.020	.010–.050
Phosphorus, ortho phosphates dissolved (P)	6	--	<.001–.040
Carbon, organic dissolved (C)	9	12.8	3.4–50
Hardness, (as $CaCO_3$)	23	353	210–500
Hardness, (as noncarbonate, $CaCO_3$)	22	45.5	.0–110
Calcium, dissolved (Ca)	23	52	29–78
Magnesium, dissolved (Mg)	23	54	28–78
Sodium, dissolved (Na)	23	77	22–110
Potassium, dissolved (K)	23	43	2.4–12.0
Chloride, dissolved (Cl)	23	21	11–52
Sulfate, dissolved (SO_4)	23	178	110–270
Fluoride, dissolved (F)	14	.4	.03–.5
Silica, dissolved (SiO_2)	23	8.0	5.7–9.6

Table 9.—Summary of chemical analyses of streamflow in Coal Creek at station 09313965, water years 1979-81—Continued

Milligrams per liter

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Arsenic, dissolved (As)	9	1.8	1.0-4.0
Barium, dissolved (Ba)	2	--	100-100
Boron, dissolved (B)	14	141	70-230
Cadmium, dissolved (Cd)	3	--	<1
Chromium, dissolved (Cr)	7	--	<10-<20
Copper, dissolved (Cu)	3	--	<2-30
Iron, dissolved (Fe)	14	--	<10-86
Lead, dissolved (Pb)	9	--	<1-19
Lithium, dissolved (Li)	8	39	20-50
Manganese, dissolved (Mn)	14	23	2.0-80
Mercury, dissolved (Hg)	3	--	<.1-5
Nickel, dissolved (Ni)	3	--	<1-2
Selenium, dissolved (Se)	9	--	<1-4.0
Strontium, dissolved (Sr)	8	572	470-720
Zinc, dissolved (Zn)	9	--	<3-70
Phenols	9	--	<1-35

[1]Fixed-end-point determined by titration in the field.

The suspended-sediment concentrations in 13 streamflow samples collected during the 3 water years of monitoring at station 09313965 ranged from 3 milligrams per liter on July 12, 1981 to 2,710 milligrams per liter August 12, 1981. Instantaneous suspended-sediment loads calculated for station 09313965 during the 1979-81 water years are summarized as follows:

Water year	Suspended-sediment loads (tons/day) Minimum	Maximum
1979	0.21	0.48
1980	.04	302
1981	Less than .01	6.4

Coal was only 0.4 percent of the stream-bottom sediments sampled.

Two samples of benthic invertebrates at station 09313965 during water year 1980 showed about the same diversity as the one benthic invertebrate sampled during water year 1979. (See Lines and Plantz, 1981, table 2.) According to Lines and Plantz (1981, p. 23), the diversity indicates a fairly healthy stream-bottom environment. Four samples of phytoplankton during water year 1981 all had a fairly uniform distribution of green algae (U.S. Geological Survey, 1982, p. 265). This probably reflects the fairly good chemical quality of the streamflow, as indicated by its dissolved-solids concentration (table 9).

Soldier Creek

The Soldier Creek drainage basin is adjacent to and east of the Coal Creek basin. Like Coal Creek, Soldier Creek originates near the crest of the Book Cliffs, but at a somewhat lower altitude (about 8,800 feet). Soldier Creek also has cut a canyon through Cretaceous formations, and it also meanders over the Mancos Shale to the Price River. Station 09313975 (pl. 1, table 1) is on the Blackhawk Formation at an altitude of 6,650 feet.

The Soldier Canyon Mine was in operation during water years 1979-84. Most of the water produced in the mine is consumed in the mining operations; however, a small, but unknown quantity is discharged intermittently to Soldier Creek.

Station 09313975 was operated seasonally during the 1979-84 water years. Maximum, minimum, and average daily mean flow in Soldier Creek is shown in figure 15. Most of the flow is during April-June, and it results chiefly from snowmelt in the higher altitudes of the drainage basin. The short-term increases in flow during June-November resulted from thunderstorms in the basin. The maximum peak flow recorded at station 09313975 during the seasonal record for water years 1979-84 was 472 cubic feet per second on September 23, 1981, and it resulted from a thunderstorm.

Base-flow measurements in Soldier Creek upstream from station 09313975 are related to geology in figure 16. The maximum values indicate that Soldier Creek loses flow slightly where it crosses the Castlegate Sandstone or the upper part of the Blackhawk Formation, but it gains flow substantially from the lower part of the Blackhawk. The minimum and average values indicate a consistent gain from the Castlegate and Blackhawk. If there was any discharge from the Soldier Canyon Mine during the base-flow measurements, it was negligible.

The chemical quality of the water in Soldier Creek is similar to that of the water in Coal Creek; however, according to Lines and Plantz (1981, p. 24), there are some notable differences during low-flow conditions. They suggest that this probably indicates a difference in some sources of ground-water discharge in the two basins. The dissolved-solids concentrations in 31 streamflow samples collected from Soldier Creek at station 09313975 ranged from 280 to 710 milligrams per liter, with a mean of 533 milligrams per liter (table 10). Sodium, magnesium, and calcium were the dominant cations, and bicarbonate and sulfate were the dominant anions. Of the trace elements that were analyzed, only manganese was found in concentrations that exceeded the criteria established by the U.S. Environmental Protection Agency (1976) for drinking-water supplies. The maximum concentration of manganese was 60 micrograms per liter, compared to a criterion of 50 micrograms per liter. The maximum phenol concentration was 38 micrograms per liter, compared to a criterion of 1 microgram per liter.

The suspended-sediment concentrations in 13 streamflow samples collected at station 09313975 ranged from 6 milligrams per liter on July 9, 1981, to 406 milligrams per liter on August 12th of the same year. Coal was 0.3 percent of the stream-bottom sediments sampled.

Six samples of benthic invertebrates were collected at station 09313975 during the 1979-80 and 1982 water years. The samples for water year 1980 showed about the same diversity as those for water year 1979 (Lines and Plantz, 1981, p. 27); and the samples in both water years had fairly good diversities of benthic invertebrates. This might have been indicative of an unpolluted stream-bottom environment. The benthic invertebrates sampled during water year 1982 were not fully evaluated. Five samples of phytoplankton were collected during water year 1981. Blue-green algae were well dispersed in those samples (U.S. Geological Survey, 1982, p. 271) which indicates fairly good chemical quality.

Dugout Creek

Dugout Creek is a tributary of Grassy Trail Creek, which is discussed in the following section. Dugout Creek originates near the crest of the Book Cliffs at an altitude of about 8,800 feet. The stream has cut a steep canyon through most of the formations shown on figure 1, as it descends about 1,800 feet to the base of the Book Cliffs, whereupon it meanders over a relatively low gradient on the Mancos Shale before joining Grassy Trail Creek at about 5,500 feet. Station 09313985 (pl. 1, table 1) is at 6,960 feet on the coal-bearing Blackhawk Formation.

No mines were active in the Dugout Creek basin during the monitoring period at station 09313985. There are several thousand acres of leased Federal coal in the basin (pl. 1), however, some exploratory mining was started upstream from the station in recent years. The proposed (1985) Sage Point-Dugout Canyon Mine will have portals in Dugout Canyon.

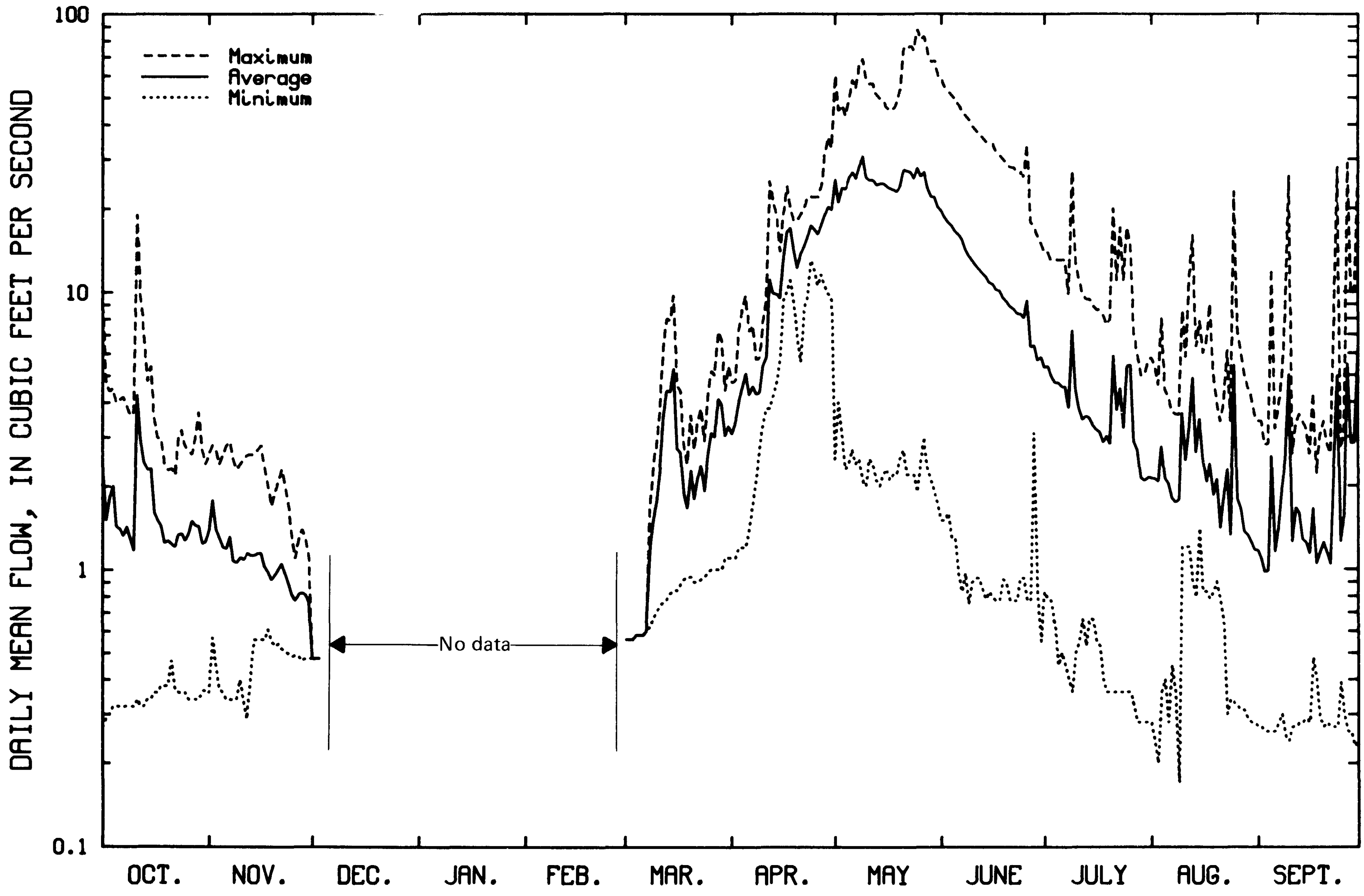

Figure 15.—Maximum, average, and minimum daily mean flow of Soldier Creek at station 09313975, seasonal record for water years 1979-84.

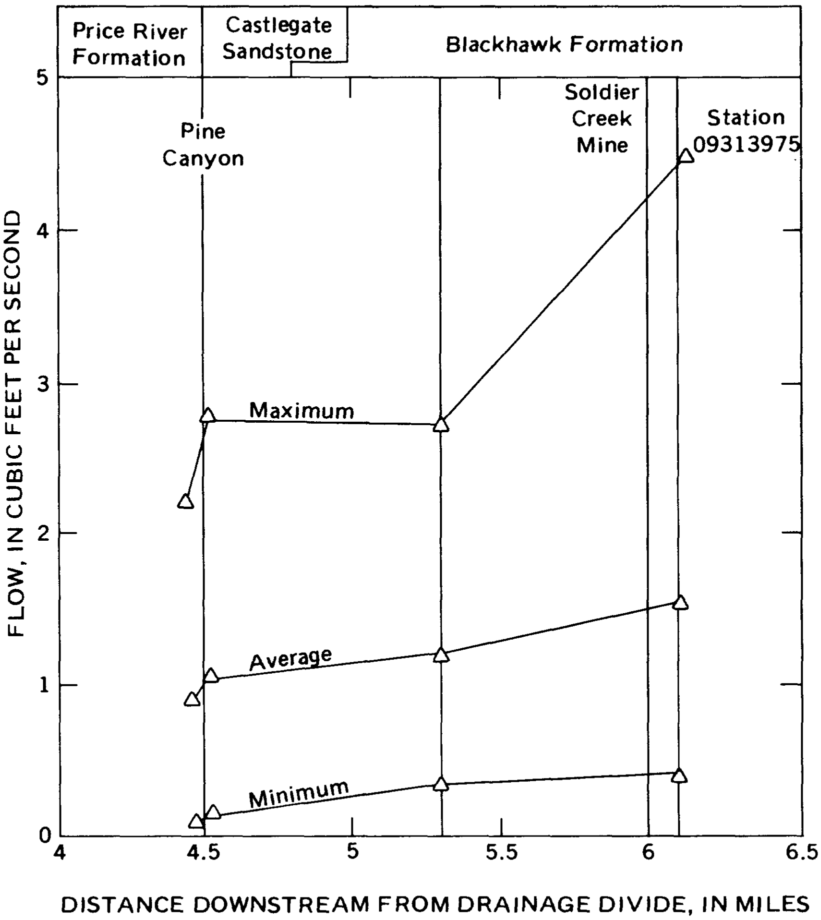

Figure 16.—Base flow of Soldier Creek as related to geology (based on 10 measurements made at each site from August 1978 to September 1984).

Table 10.—Summary of chemical analyses of streamflow in Soldier Creek at station 09313975, water years 1979-84
[<indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	33	6.3	0.35-54
Water temperature (degrees Celsius)	31	15.5	.0-25.5
Specific conductance (microsiemens per centimeter at 25° Celsius)	33	840	500-1,190
pH (units)	31	--	8.1-8.8
Sodium-adsorption ratio	33	.2	.6-4.0
Milligrams per liter			
Dissolved solids, sum of constituents	31	533	280-710
Oxygen, dissolved (O_2)	31	8.0	6.7-11.5
Carbon dioxide, dissolved (CO_2)	21	1.7	.8-3.8
Alkalinity ($CaCO_3$)[1]	23	310	210-440
Bicarbonate (HCO_3)[1]	21	209	240-500
Carbonate (CO_3)[1]	21	13.4	0-26
Nitrogen, dissolved (N)	9	.53	.20-1.2
Nitrogen, organic dissolved (N)	7	.38	.18-.85
Nitrogen, ammonia dissolved (N)	7	--	<.01-.130
Nitrogen, nitrite dissolved (N)	7	--	<.01-.010
Nitrogen, nitrate dissolved (N)	7	--	<.05-.14
Nitrogen, nitrite + nitrate dissolved (N)	20	--	<.01-.24
Phosphorus, dissolved (P)	13	--	<.010-.080
Phosphorus, ortho phosphates dissolved (P)	7	--	<.001-.040
Carbon, organic dissolved (C)	18	8.2	2.2-32
Hardness, (as $CaCO_3$)	33	302	150-390
Hardness, (as noncarbonate, $CaCO_3$)	22	1.0	.0-47
Calcium, dissolved (Ca)	33	47.7	31-65
Magnesium, dissolved (Mg)	33	44.4	18-58
Sodium, dissolved (Na)	33	79.6	21-150
Potassium, dissolved (K)	33	4.0	1.5-8.6
Chloride, dissolved (Cl)	33	16.1	5.2-30
Sulfate, dissolved (SO_4)	33	122	44-230
Fluoride, dissolved (F)	25	.47	.20-.70
Silica, dissolved (SiO_2)	33	8.1	6.6-9.6

Table 10.—Summary of chemical analyses of streamflow in Soldier Creek at station 09313975, water years 1979-84—Continued

Milligrams per liter

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Arsenic, dissolved (As)	16	—	<1-2.0
Barium, dissolved (Ba)	5	—	<100-290
Boron, dissolved (B)	24	—	<40-310
Cadmium, dissolved (Cd)	10	—	<1
Chromium, dissolved (Cr)	13	—	<10
Copper, dissolved (Cu)	10	—	<2-3
Iron, dissolved (Fe)	25	—	<10-140
Lead, dissolved (Pb)	14	—	<1-18
Lithium, dissolved (Li)	11	36.6	20-65
Manganese, dissolved (Mn)	23	338	7-60
Mercury, dissolved (Hg)	10	—	<.1-1.3
Nickel, dissolved (Ni)	9	—	<1-13
Selenium, dissolved (Se)	16	—	<1-3
Strontium, dissolved (Sr)	11	483	340-630
Zinc, dissolved (Zn)	16	—	<3-60
Phenols	15	—	<1-38

[1]Fixed-end-point determined by titration in the field.

Seasonal records were collected at station 09313985, during water years 1980-81. The maximum, minimum, and average daily mean flow shown in figure 17 indicate that most of the recorded flow in Dugout Creek is during May and June, resulting from snowmelt in the higher altitudes. The short-term increases in discharge during August and September, however, indicate that considerable flow in the creek results from thunderstorms. The maximum peak flow recorded at the station was 127 cubic feet per second on September 5, 1981 (table 3), and that flow resulted from a thunderstorm.

The chemical quality of the streamflow in Dugout Creek is apparently slightly better than that of Coal and Soldier Creeks. Dissolved-solids concentrations in 15 streamflow samples collected at station 09313985 during water years 1980-81 ranged from 350 to 480 milligrams per liter, with a mean of 396 milligrams per liter (table 11). Calcium and magnesium were the dominant dissolved cations and bicarbonate was the dominant dissolved anion. None of the trace elements that were analyzed were found in concentrations that exceed the criteria established by the U.S. Environmental Protection Agency (1976) for drinking-water supplies. The maximum phenol concentration was 10 micrograms per liter, compared to a criterion of 1 microgram per liter.

Suspended-sediment concentrations in 11 streamflow samples collected at station 09313985 during water years 1980-81 ranged from 5 milligrams per liter on July 9, 1981 to 1,000 milligrams per liter on April 30, 1980. Instantaneous suspended-sediment loads calculated for the station ranged from 0.01 to 38 tons per day during water year 1980 and from less than 0.01 to 0.08 tons per day during water year 1981.

Two samples of benthic invertebrates collected at station 09313985 during water year 1980 showed good diversity (U.S. Geological Survey, 1981, p. 272). Five samples of phytoplankton collected at the same site during water year 1981 showed a fairly uniform distribution of green algae (U.S. Geological Survey, 1982, p. 276).

Grassy Trail Creek

Grassy Trail Creek originates near the crest of the Book Cliffs at an altitude of about 10,000 feet. The channel has cut through most of the formations shown in figure 1 as it descends steeply more than 3,000 feet to the base of the Book Cliffs near the town of Sunnyside. From there the channel is on the Mancos Shale, until its confluence with the Price River. Station 09314340 (pl. 1, table 1) is at Sunnyside at an altitude of 6,540 feet. The Sunnyside Mines (pl. 1) were in operation in the Grassy Trail Creek basin during the monitoring period at the station.

According to Lines and Plantz (1981, p. 28), about 1 cubic foot per second of unconsumed mine water is discharged to Grassy Trail Creek upstream from station 09314340. The mine waters reportedly have dissolved-solids concentrations as large as 1,600 milligrams per liter (Waddell and others, 1981, table 8).

The annual mean flow in Grassy Trail Creek recorded at station 09314340 ranged from 2.43 cubic feet per second during water year 1981 to 24.2 cubic feet per second during water year 1983, with an average of 9.89 cubic feet

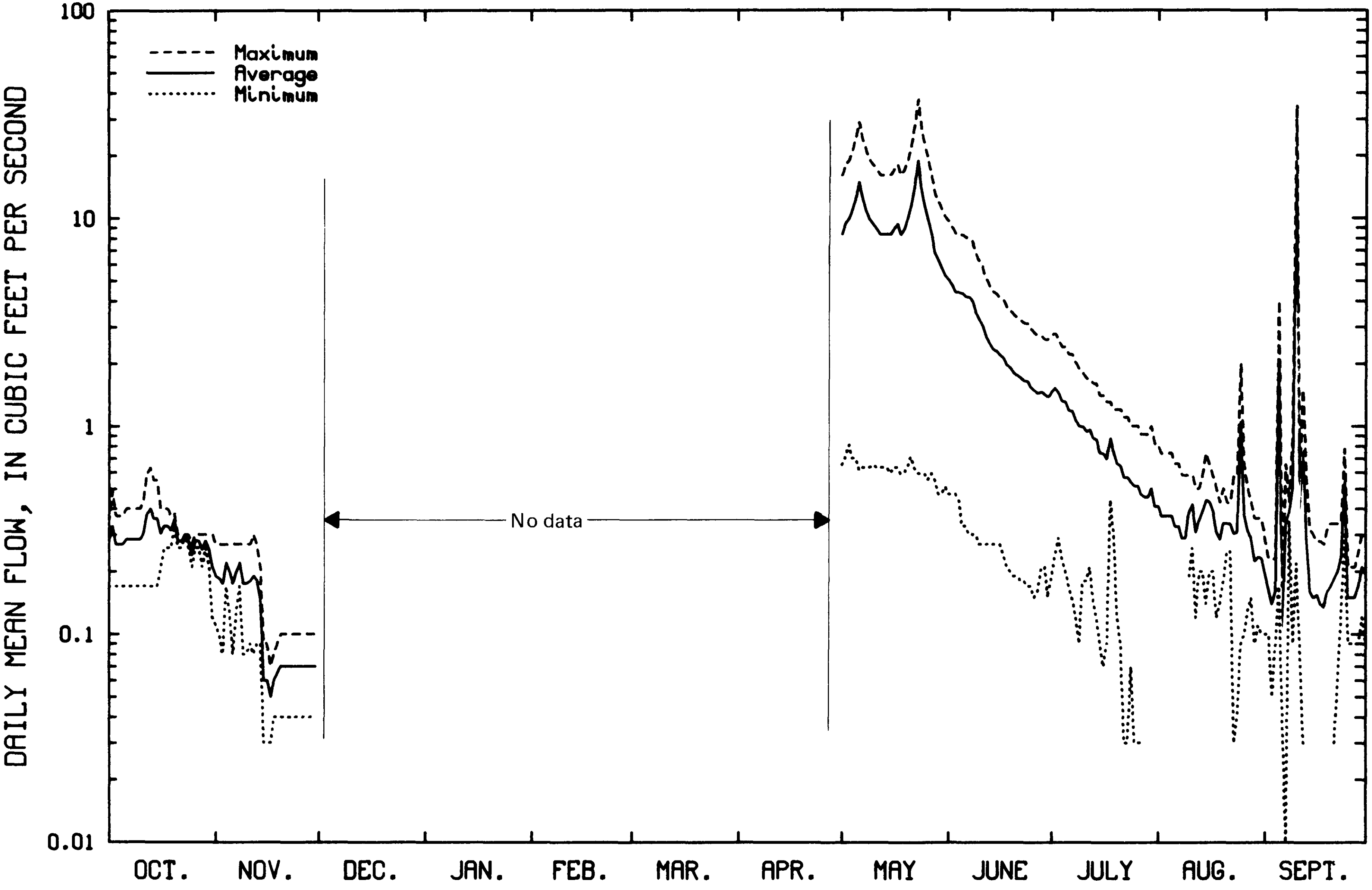

Figure 17.—Maximum, average, and minimum daily mean flow of Dugout Creek at station 09313985, seasonal record for water years 1980-81.

Table 11.—Summary of chemical analyses of streamflow in Dugout Creek at station 09313985, water years 1980-81

[< indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	16	1.8	0.05-19.0
Water temperature (degrees Celsius)	16	10.3	1.0-20.5
Specific conductance (microsiemens per centimeter at 25° Celsius)	16	667	590-820
pH (units)	16	--	8.1-8.6
Sodium-adsorption ratio	16	.6	.4-0.6
Milligrams per liter			
Dissolved solids, sum of constituents	15	396	350-480
Oxygen, dissolved (O_2)	16	8.7	7.0-10.8
Carbon dioxide, dissolved (CO_2)	15	2.6	1.3-5.3
Alkalinity ($CaCO_3$)[1]	15	287	240-350
Bicarbonate (HCO_3)[1]	14	347	320-420
Carbonate (CO_3)[1]	14	2.6	.0-8.0
Nitrogen, dissolved (N)	6	.38	.24-.65
Nitrogen, organic dissolved (N)	3	.37	.32-.43
Nitrogen, ammonia dissolved (N)	3	--	<.01-.040
Nitrogen, nitrite dissolved (N)	3	--	<.01
Nitrogen, nitrate dissolved (N)	3	--	<.05-.21
Nitrogen, nitrite + nitrate dissolved (N)	6	--	<.01-.21
Phosphorus, dissolved (P)	3	.02	.010-.020
Phosphorus, ortho phosphates dissolved (P)	3	--	<.001-.060
Carbon, organic dissolved (C)	6	9.1	2.9-17
Hardness, (as $CaCO_3$)	16	325	300-380
Hardness, (as noncarbonate, $CaCO_3$)	15	38	16-65
Calcium, dissolved (Ca)	16	58	50-68
Magnesium, dissolved (Mg)	16	44	36-52
Sodium, dissolved (Na)	16	23	15-27
Potassium, dissolved (K)	16	2.9	1.7-4.1
Chloride, dissolved (Cl)	16	5.9	4.9-6.8
Sulfate, dissolved (SO_4)	16	81	51-110
Fluoride, dissolved (F)	11	.3	.2-.5
Silica, dissolved (SiO_2)	16	8.7	7.5-9.8

Table 11.—Summary of chemical analyses of streamflow in Dugout Creek at station 09313985, water years 1980-81—Continued

Milligrams per liter

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Arsenic, dissolved (As)	6	1.2	1.0-2.0
Barium, dissolved (Ba)	2	--	<100-100
Boron, dissolved (B)	11	—	<10-150
Cadmium, dissolved (Cd)	3	--	<1
Chromium, dissolved (Cr)	6	—	<10
Copper, dissolved (Cu)	3	--	<2
Iron, dissolved (Fe)	11	—	<10-20
Lead, dissolved (Pb)	6	--	<1-4
Lithium, dissolved (Li)	5	20	10-30
Manganese, dissolved (Mn)	11	--	<1-25
Mercury, dissolved (Hg)	3	—	<.1-.2
Nickel, dissolved (Ni)	3	--	<1-2.0
Selenium, dissolved (Se)	6	—	<1-1.0
Strontium, dissolved (Sr)	5	354	320-400
Zinc, dissolved (Zn)	6	—	<3-4
Phenols	6	--	<1-10

[1]Fixed-end-point determined by titration in the field.

per second (table 3). The maximum peak flow recorded was 631 cubic feet per second on May 31, 1983. The maximum, minimum, and average daily mean flow is shown in figure 18. The runoff in Grassy Trail Creek peaks in late May, somewhat later than the corresponding peaks for Dugout, Soldier, and Coal Creeks, which also head near the crest of the Book Cliffs. More snow accummulates in the Grassy Trail Creek basin because the creek originates at a higher altitude than do the other streams, and the snow begins to melt later in the spring.

The base flow in Grassy Trail Creek increases substantially between Grassy Trail Reservoir and station 09314340 (fig. 19). The increase is attributed to ground-water inflow from rocks younger than the Castlegate Sandstone and to intermittent discharges of mine water (Lines and Plantz, 1981, p. 28). The intermittent discharge of mine water results in considerable variations in base flow downstream from the Sunnyside Mines.

The dissolved-solids concentrations in 47 streamflow samples collected at station 09314340 during water years 1979-84 ranged from 330 to 1,900 milligrams per liter; with a mean concentration of 988 milligrams per liter (table 12). A seasonal variation in the ratios of dissolved ions in the streamflow (Lines and Plantz, 1981, fig. 17) is related to the quantity of dissolved-solids, which in turn is related to seasonal variation of streamflow and inflow of mine water. In general, however, calcium and magnesium were the dominant cations, and bicarbonate and sulfate were the dominant anions. The mine water may possibly be a source of the sulfate. Of the trace elements that were analyzed, only lead was found in concentrations that exceeded the criteria of the U.S. Environmental Protection Agency (1976, p. 5) for drinking-water supplies. The maximum concentration of lead was 55 micrograms per liter, compared to a criterion of 50 micrograms per liter. The mine water also may be a source of lead. The maximum concentration of phenol was about 40 micrograms per liter, compared to a criterion of 1 microgram per liter.

Suspended-sediment concentrations in 25 streamflow samples collected from Grassy Trail Creek at station 09314340 ranged from 4 milligrams per liter on March 13, 1979, and December 9, 1980, to 1,640 milligrams per liter on May 22, 1980. The largest calculated instantaneous suspended-sediment load was 518 tons per day on May 22, 1980. Coal was about 17 percent of the stream-bottom sediments that were sampled. The principal source of the coal probably is the mine water because the stream contains considerable quantities of suspended coal particles during periods of mine dewatering.

Nine samples of benthic invertebrates collected at station 09314340 during water years 1979, 1980, and 1982 had good diversity. (See for example Lines and Plantz, 1981, table 2 and p. 32.) Five samples of phytoplankton collected during water year 1981 probably reflected the variable chemical quality of the streamflow. Green algae had a uniform distribution in the five samples; however, blue-green algae appeared in relatively larger numbers in three of the samples (U. S. Geological Survey, 1982, p. 285).

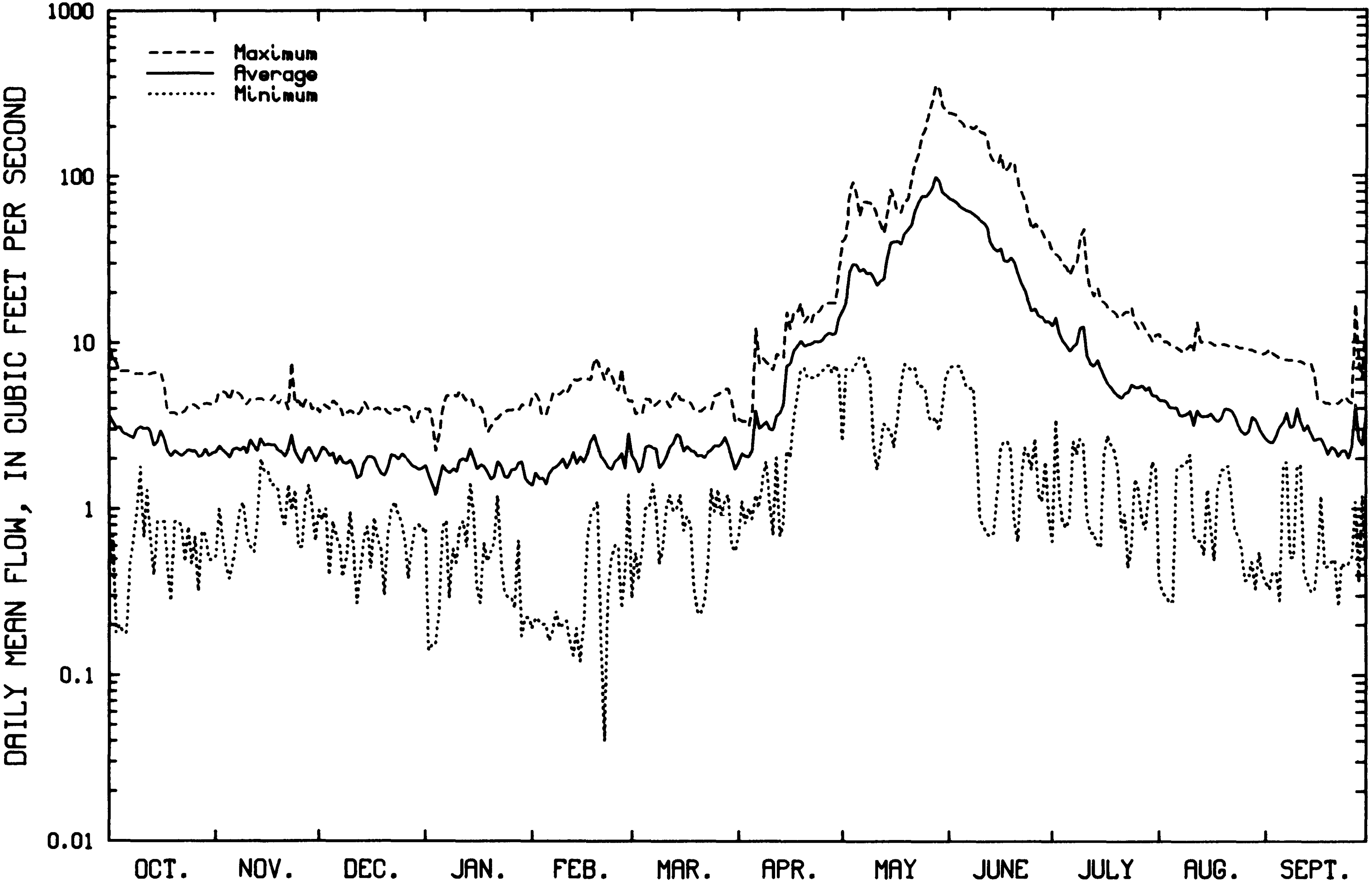

Figure 18.—Maximum, average, and minimum daily mean flow of Grassy Trail Creek at station 09314340, water years 1979-84.

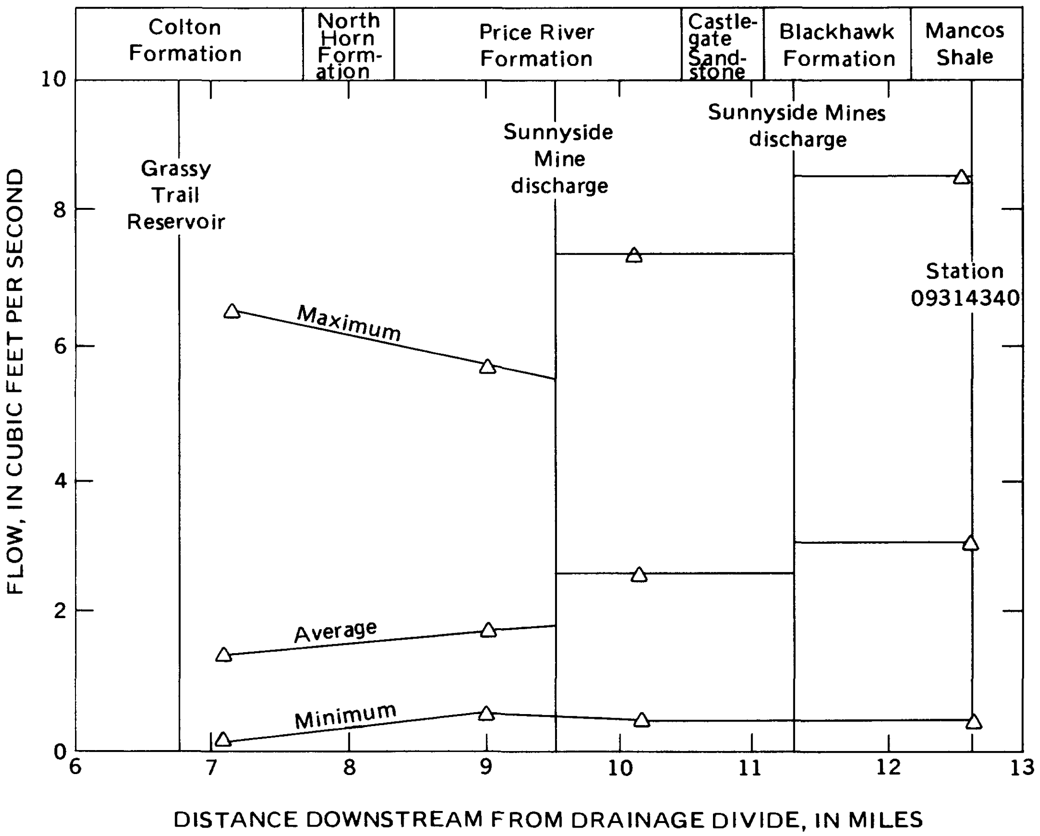

Figure 19.—Base flow of Grassy Trail Creek as related to geology (based on 10 measurements made at each site from August 1978 to September 1984).

Table 12.—Summary of chemical analyses of streamflow in Grassy Trail Creek at station 09314340, water years 1979-84

[< indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	49	10.8	0.15-204
Water temperature (degrees Celsius)	49	10.9	.0-23.0
Specific conductance (microsiemens per centimeter at 25° Celsius)	49	1,420	510-2,600
pH (units)	49	--	8.1-9.1
Sodium-adsorption ratio	49	6.0	.6-14
Milligrams per liter			
Dissolved solids, sum of constituents	47	988	330-1,900
Oxygen, dissolved (O_2)	49	8.9	6.6-11.7
Carbon dioxide, dissolved (CO_2)	39	1.7	.6-3.9
Alkalinity ($CaCO_3$)[1]	39	420	240-670
Bicarbonate (HCO_3)[1]	39	471	250-770
Carbonate (CO_3)[1]	39	22.3	.0-75
Nitrogen, dissolved (N)	14	0.62	.26-1.1
Nitrogen, organic dissolved (N)	10	.32	.16-0.63
Nitrogen, ammonia dissolved (N)	10	--	<.01-.210
Nitrogen, nitrite dissolved (N)	10	--	<.01-.040
Nitrogen, nitrate dissolved (N)	10	--	<.05-.35
Nitrogen, nitrite + nitrate dissolved (N)	23	--	<.01-.36
Phosphorus, dissolved (P)	13	--	<.01-.060
Phosphorus, ortho phosphates dissolved (P)	10	--	<.001-.040
Carbon, organic dissolved (C)	23	5.3	1.6-22
Hardness, (as $CaCO_3$)	49	302	220-420
Hardness, (as noncarbonate, $CaCO_3$)	39	10.4	.0-83
Calcium, dissolved (Ca)	49	44.9	24-76
Magnesium, dissolved (Mg)	49	45.9	33-64
Sodium, dissolved (Na)	49	216	23-530
Potassium, dissolved (K)	49	4.4	1.3-15
Chloride, dissolved (Cl)	49	23.8	2.6-77
Sulfate, dissolved (SO_4)	49	355	59-730
Fluoride, dissolved (F)	32	.52	.10-1.0
Silica, dissolved (SiO_2)	49	10.7	4.2-16

Table 12.—Summary of chemical analyses of streamflow in Grassy Trail Creek at station 09314340, water years 1979-84—Continued

	Properties and constituents	No. of analyses	Mean	Minimum-maximum
Milligrams per liter	Arsenic, dissolved (As)	18	—	<1-3
	Barium, dissolved (Ba)	3	--	<100-100
	Boron, dissolved (B)	32	—	<20-370
	Cadmium, dissolved (Cd)	8	--	<1
	Chromium, dissolved (Cr)	12	—	<10-40
	Copper, dissolved (Cu)	8	--	<2-2.0
	Iron, dissolved (Fe)	32	—	<10-40
	Lead, dissolved (Pb)	12	--	<1-55
	Lithium, dissolved (Li)	15	—	<10-80
	Manganese, dissolved (Mn)	32	--	<1-30
	Mercury, dissolved (Hg)	8	—	<.1-1.4
	Nickel, dissolved (Ni)	8	--	<1-4.0
	Selenium, dissolved (Se)	18	—	<1-2.0
	Strontium, dissolved (Sr)	15	390	260-610
	Zinc, dissolved (Zn)	17	—	<3-40
	Phenols	20	--	<40

[1]Fixed-end-point determined by titration in the field.

Horse Canyon Creek

Horse Canyon creek originates near the crest of the Book Cliffs at an altitude of about 9,600 feet. The channel has cut a steep canyon through most of the formations shown in figure 1 as it descends steeply more than 3,000 feet to the base of the Book Cliffs near the Geneva Mine (pl. 1). Station 09314374 (pl. 1, table 1) is near the lower end of Horse Canyon at an altitude of about 6,200 feet.

The portal of the Geneva Mine (pl. 1) is in Horse Canyon, but the mine workings extend into adjacent drainage basins. The mine was in operation during monitoring at station 09314374. According to Lines and Plantz (1981, p. 32) an average of about 0.2 cubic feet per second may be discharged intermittently from the Geneva Mine to Horse Canyon creek just upstream from the station.

The annual mean flow in Horse Canyon creek at station 09314374 during the monitoring period ranged from 0.29 cubic feet per second during water year 1981 to 0.43 cubic feet per second during water year 1980 (table 3). Flow at the station is intermittent and quite variable as indicated in figure 20. The variation is due chiefly to intermittent discharge of water from the Geneva Mine to Horse Canyon creek. The maximum peak flow recorded was 93.0 cubic feet per second on September 5, 1981, which resulted from a thunderstorm.

Base-flow measurements along Horse Canyon creek (fig. 21) show that the creek was dry at least once at each site. The average values indicate some ground-water inflow to the creek from the Price River, Castlegate, or Blackhawk Formations. Both the average and maximum values, however, reflect the discharge of water to the creek from the Geneva Mine.

Most of the streamflow samples collected at station 09314374 for chemical analyses apparently were mostly or virtually all mine water. The dissolved-solids concentrations in 33 samples ranged from 970 to 4,200 milligrams per liter, with a mean of 1,890 milligrams per liter (table 13). Sodium and sulfate were the dominant ions in virtually all the samples. Strontium was found in concentrations as large as 2,000 micrograms per liter. Of the trace elements that were analyzed only manganese exceeded the criteria established by the U.S. Environmental Protection Agency (1976) for drinking-water supplies. The maximum concentration of manganese was 540 micrograms per liter, compared to a criterion of 50 micrograms per liter. The maximum phenol concentration was 5 micrograms per liter, compared to a criterion of 1 microgram per liter.

Suspended-sediment concentrations in 21 streamflow samples collected from Horse Canyon creek at station 09314374 during water years 1979-81 ranged from 2 milligrams per liter on January 16, 1981 to 2,270 milligrams per liter on May 4, 1981. The smaller concentrations reflect low-flow periods, whereas the larger concentrations generally reflect greater turbidity during periods of high flow resulting from snowmelt or thunderstorms. Calculated suspended-sediment loads ranged from less than 0.01 to 1.3 tons per day in water year 1979, from less than 0.01 to 0.29 tons per day during water year 1980, and from less than 0.01 to 2.0 tons per day during water year 1981. Coal was only 0.5 percent of the stream-bottom sediments sampled.

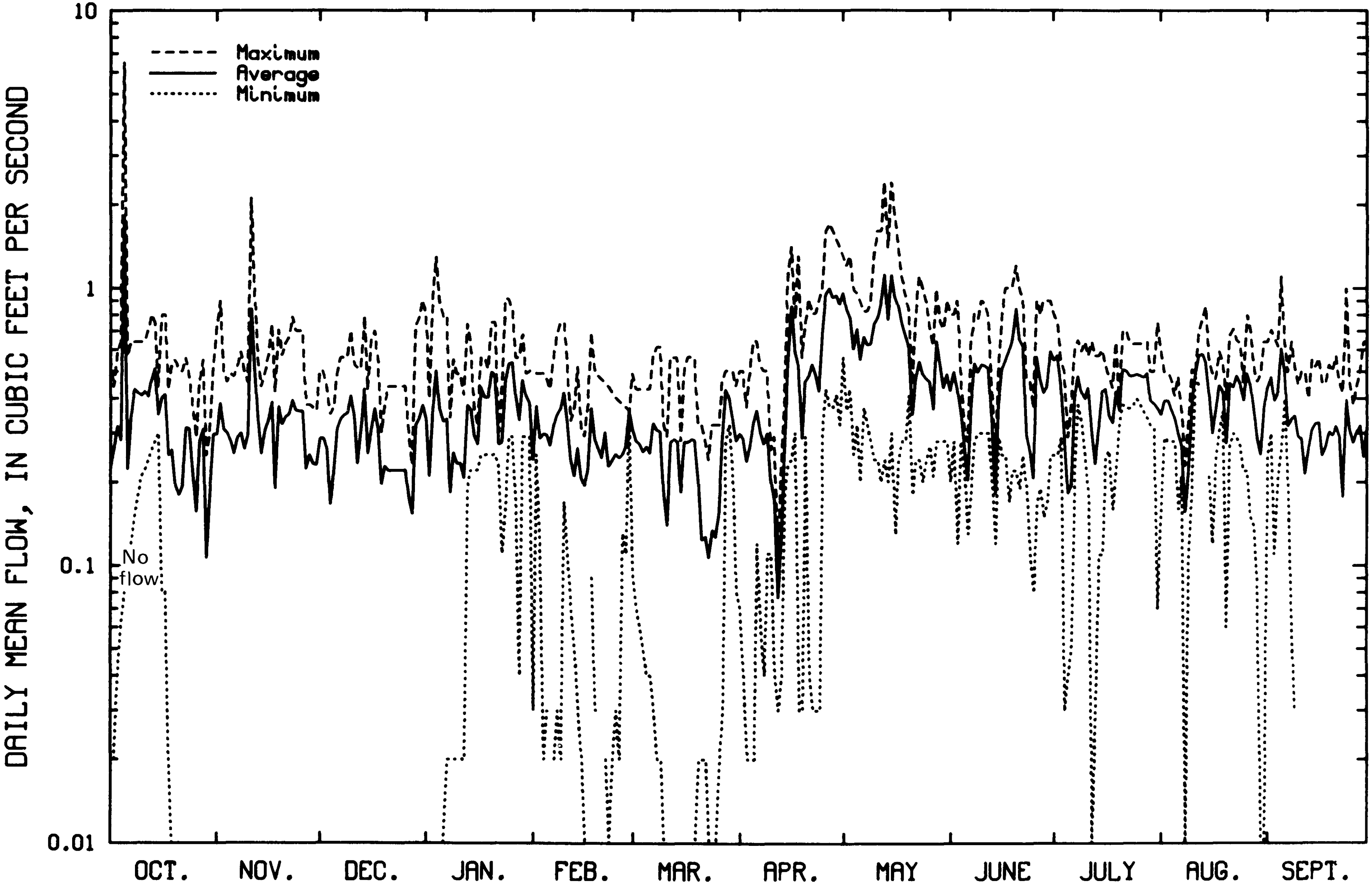

Figure 20.—Maximum, average, and minimum daily mean flow of Horse Canyon creek at station 09314374, water years 1979 81.

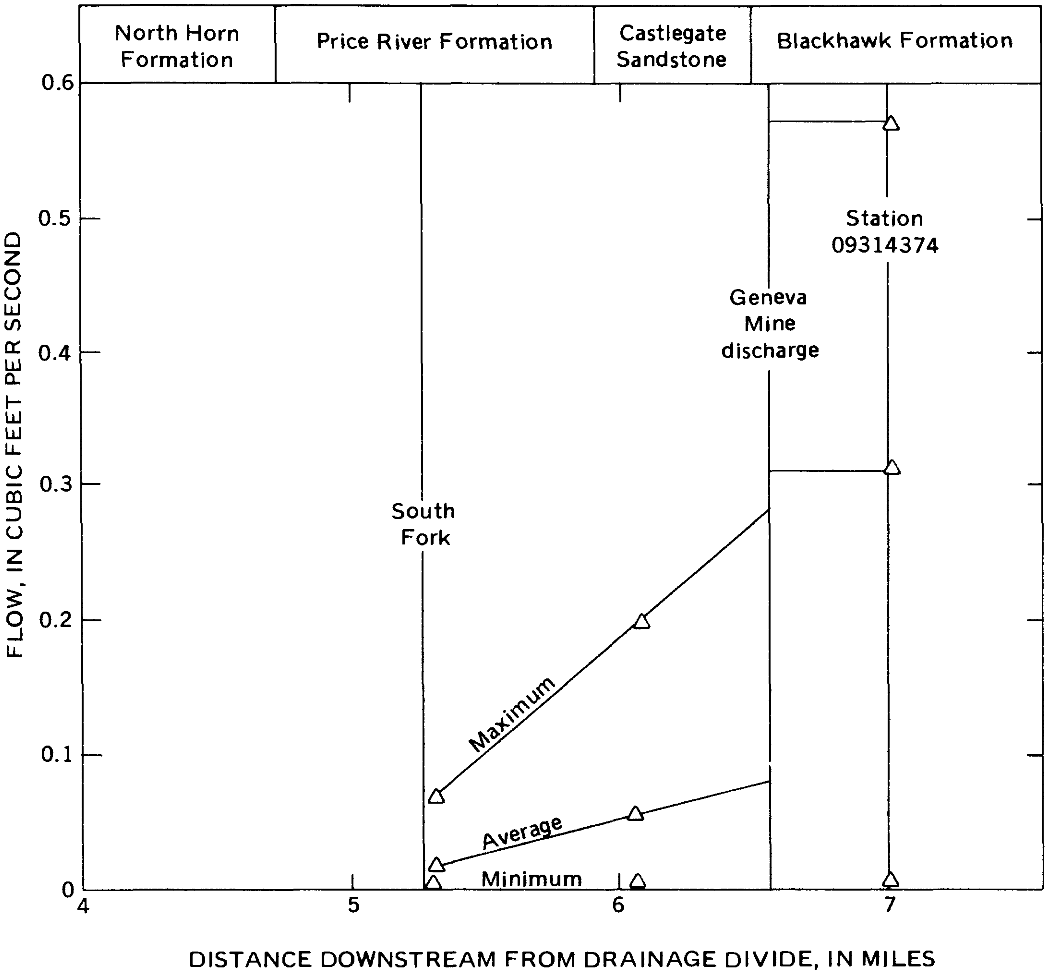

Figure 21.—Base flow of Horse Canyon creek as related to geology (based on 7 measurements made at each site from August 1978 to August 1981).

Table 13.—Summary of chemical analyses of streamflow in Horse Canyon creek at station 09314374, water year 1979-81

[< indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	33	0.34	0.01-0.61
Water temperature (degrees Celsius)	33	17.3	6.0-27.5
Specific conductance (microsiemens per centimeter at 25° Celsius)	33	2,600	1,390-7,000
pH (units)	33	--	8.2-8.7
Sodium-adsorption ratio	33	6.1	1.0-12.0
Milligrams per liter			
Dissolved solids, sum of constituents	33	1,890	970-4,200
Oxygen, dissolved (O_2)	33	7.8	6.0-10.6
Carbon dioxide, dissolved (CO_2)	33	2.1	1.1-4.2
Alkalinity ($CaCO_3$)[1]	33	370	279-480
Bicarbonate (HCO_3)[1]	32	426	340-570
Carbonate (CO_3)[1]	32	13.9	.0-26.0
Nitrogen, dissolved (N)	9	1.25	.44-22.0
Nitrogen, organic dissolved (N)	7	.30	.05-.49
Nitrogen, ammonia dissolved (N)	7	--	<.01-.610
Nitrogen, nitrite dissolved (N)	7	--	<.01-.060
Nitrogen, nitrate dissolved (N)	7	--	<.13-1.20
Nitrogen, nitrite + nitrate dissolved (N)	11	.61	.13-1.20
Phosphorus, dissolved (P)	4	--	<.01-.050
Phosphorus, ortho phosphates dissolved (P)	7	--	<.001-.020
Carbon, organic dissolved (C)	11	6.4	1.4-18.0
Hardness, (as $CaCO_3$)	33	709	420-1,600
Hardness, (as noncarbonate, $CaCO_3$)	33	340	100-1,300
Calcium, dissolved (Ca)	33	93	51-210
Magnesium, dissolved (Mg)	33	116	65-260
Sodium, dissolved (Na)	33	359	130-1,000
Potassium, dissolved (K)	33	8.6	4.6-26
Chloride, dissolved (Cl)	33	80	18-1,500
Sulfate, dissolved (SO_4)	33	974	440-1,300
Fluoride, dissolved (F)	16	.30	.20-.50
Silica, dissolved (SiO_2)	33	11.3	7.1-16.0

Table 13.—Summary of chemical analyses of streamflow in Horse Canyon creek at station 09314374, water year 1979-81—Continued

Milligrams per liter

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Arsenic, dissolved (As)	8	--	<1-2.0
Barium, dissolved (Ba)	2	--	100-100
Boron, dissolved (B)	16	--	<20-490
Cadmium, dissolved (Cd)	1	--	1
Chromium, dissolved (Cr)	6	--	<20
Copper, dissolved (Cu)	1	--	2
Iron, dissolved (Fe)	16	--	<10-<110
Lead, dissolved (Pb)	7	--	<1-47
Lithium, dissolved (Li)	9	--	<10-630
Manganese, dissolved (Mn)	16	--	<1-540
Mercury, dissolved (Hg)	1	--	<.1
Nickel, dissolved (Ni)	1	--	1
Selenium, dissolved (Se)	8	--	<1-5
Strontium, dissolved (Sr)	9	1,280	720-2,000
Zinc, dissolved (Zn)	9	--	<3-43
Phenols	10	--	<1-5

[1]Fixed-end-point determined by titration in the field.

Three samples of benthic invertebrates collected at station 09314374 during water year 1980 had about the same fair-to-poor diversity as those reported by Lines and Plantz, (1981, p. 35) for water year 1979. Three phytoplankton samples collected during water year 1981 (U.S. Geological Survey, 1982, p. 291) had a poor distribution of green algae, and a fairly uniform distribution of blue-green algae.

SAN RAFAEL RIVER BASIN

Huntington Creek, Crandall Canyon Creek, and Tie Fork

Huntington Creek originates on the Flagstaff Limestone at an altitude above 10,000 feet on the Wasatch Plateau. The creek has cut a deep, narrow canyon into the Flagstaff and the underlying Cretaceous formations shown on figure 1. It flows from its canyon into Castle Valley at about 5,000 feet, where it has incised the Mancos Shale. Stations 09317997 and 09318000 are on the Mancos Shale between 6,200 and 6,500 feet. Flow of the stream is regulated at several upstream reservoirs.

During the 1979 water year, monitoring was at station 09318000 (pl. 1, table 1), which was operated by Utah Power & Light Co. During the 1980 and 1981 water years, monitoring was at station 09317997 (pl. 1, table 1). Station 09317997 is 1.3 miles upstream from station 09318000, and the records of the two stations are virtually equivalent. The data collected at station 09318000 during the 1979 water year are summarized by Lines and Plantz (1981, p. 35-39). The data collected at station 09317997 during the 1980-81 water years are summarized in this report. All the data collected at both stations are published by ReMillard and others (1985, and previous editions of that report).

Crandall Canyon creek and Tie Fork, tributaries to Huntington Creek, also could be affected by coal mining. Those streams were monitored at gaging stations 09317919 and 09317920 (pl. 1, table 1). Station 09317919, which is near the mouth of Crandall Canyon, is on the Star Point Sandstone at an altitude of 7,350 feet. Station 09317920, which is near the mouth of Tie Fork, also is on the Star Point Sandstone; but it is at an altitude of about 7,400 feet. Both stations were operated continuously during the 1979 water year (see Lines and Plantz, 1981, p. 35) but only seasonally during the remainder of the monitoring period (table 1).

The Huntington Creek drainage basin is one of the more actively-mined parts of the central Utah coal-fields area. More than 20,000 acres in the basin were leased for coal mining in 1980, including the Deer Creek Mine. Most of the mine workings require dewatering, but available data indicate that a total of less than 1 cubic foot per second of mine water is discharged to Huntington Creek. The mine waters reportedly contain about 500-800 milligrams per liter of dissolved solids.

A potential exists for mine-related interbasin transfer of ground water between Huntington Creek basin and adjacent basins. For example, the Deer Creek Mine workings have been extended into the Cottonwood Creek basin, and workings of the Hiawatha Mine (pl. 1) have been extended from the Miller Creek basin into the Huntington Creek basin. Also, workings of the Belina Nos. 1 and 2 Mines probably will extend from the Mud Creek basin into the Huntington Creek basin.

Lines and Plantz (1981, fig. 20) showed that most of the annual flow in Crandall Canyon creek during the 1979 water years was from mid May to early July, probably due to melting of high-altitude snow. Figure 22 of this report, which includes records for the 1979 water year and seasonal record for water years 1980-84, indicates that the peak seasonal flow begins in late April. During the 1979 water year, the mean flow in Crandall Canyon creek at station 09317919 was 2.19 cubic feet per second (table 3). The maximum peak flow recorded in Crandall Canyon creek at station 09317919 was 97.0 cubic feet per second on May 24, 1984, which resulted from snowmelt.

The dissolved-solids concentrations in 30 streamflow samples collected from Crandall Canyon creek at station 09317919 during August 1978-September 1984 ranged from 229 to 320 milligrams per liter, with a mean of 263 milligrams per liter (table 14). Calcium, magnesium, and bicarbonate were the dominant ions in all the samples. Concentrations of none of the trace elements that were analyzed exceeded the criteria established by the Environmental Protection Agency (1976) for drinking-water supplies. The maximum phenol concentration was 25 micrograms per liter, compared to a criteria of 1 microgram per liter.

The suspended-sediment concentrations of 12 samples obtained during the monitoring period ranged from 4 to 121 milligrams per liter. The calculated instantaneous suspended-sediment loads at station 09317919 ranged from 0.08 to 0.15 tons per day during water year 1979, 0.08 to 0.92 tons per day during water year 1980, and less than 0.01 to 0.25 tons per day during water year 1981. Stream-bottom sediment sampled during water years 1981 and 1982 consisted of less than 0.6 percent coal.

Samples of benthic invertebrates and phytoplankton collected at station 09317919 probably reflect the chemical quality of the streamflow (as described earlier) in Crandall Canyon creek. Two samples of the benthic invertebrates collected during water year 1980 (U.S. Geological Survey, 1981, p. 305) had good diversity, and five samples of phytoplankton collected during water year 1981 (U.S. Geological Survey, 1982, p. 313) displayed uniform distribution of green algae.

Streamflow in Tie Fork, as in Crandall Canyon creek, occurs chiefly from snowmelt. The flow per square mile in Tie Fork however, is much less than it is in Crandall Canyon creek (table 3) because the Crandall Canyon creek basin generally is higher and receives more precipitation than the Tie Fork basin.

Station 09317920 (pl. 1, table 1), which is near the mouth of Tie Fork was operated continuously during the 1979 water year. The mean flow for that period was 2.04 cubic feet per second. The maximum, minimum, and average daily mean flow (fig. 23) reflects maximum snowmelt runoff during late April-June. The maximum peak flow was 29.0 cubic feet per second on April 30, 1980, which resulted from snowmelt.

The dissolved-solids concentrations in 22 streamflow samples collected from Tie Fork at station 09317920 during water years 1979-81 ranged from 240

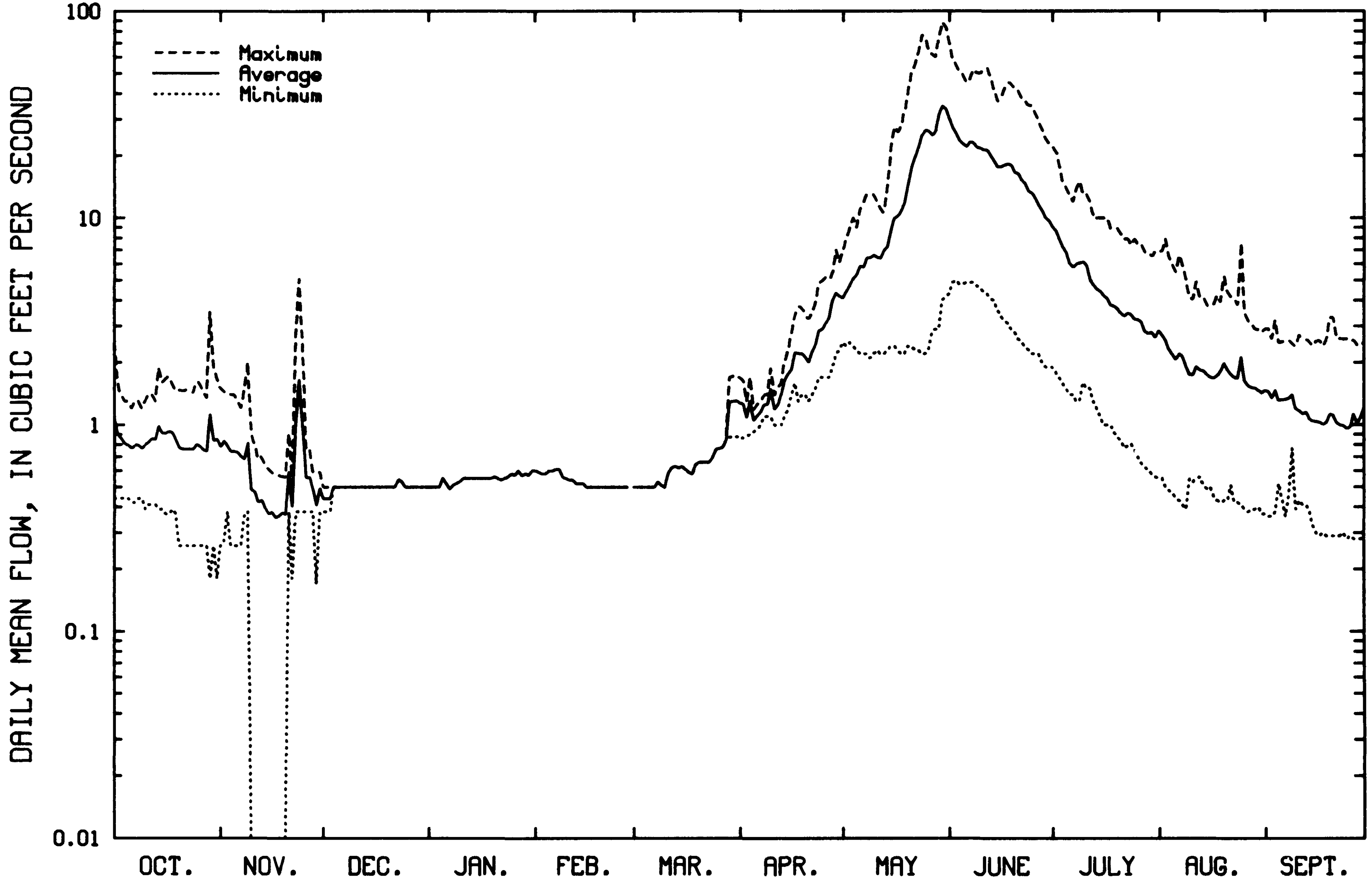

Figure 22.—Maximum, average, and minimum daily mean flow of Crandall Canyon creek at station 09317919, complete record for water year 1979 and seasonal record for water years 1980-84.

Table 14.—Summary of chemical analyses of streamflow in Crandall Canyon creek at station 09317919, water years 1979–84

[<indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	30	4.7	0.38-49
Water temperature (degrees Celsius)	30	11.5	.0-25.5
Specific conductance (microsiemens per centimeter at 25^{o} Celsius)	30	464	350-580
pH (units)	30	--	8.1-8.7
Sodium-adsorption ratio	30	.12	.1-.3
Milligrams per liter			
Dissolved solids, sum of constituents	30	263	229-320
Oxygen, dissolved (O_2)	30	8.8	7.1-111
Carbon dioxide, dissolved (CO_2)	20	1.3	.7-2.5
Alkalinity ($CaCO_3$)[1]	20	226	195-280
Bicarbonate (HCO_3)[1]	20	262	230-330
Carbonate (CO_3)[1]	20	7.8	.0-20
Nitrogen, dissolved (N)	10	.50	.19-1.1
Nitrogen, organic dissolved (N)	6	.38	.14-1.1
Nitrogen, ammonia dissolved (N)	6	--	<.01-0.070
Nitrogen, nitrite dissolved (N)	6	--	<.010
Nitrogen, nitrate dissolved (N)	6	--	<.05-.05
Nitrogen, nitrite + nitrate dissolved (N)	18	--	<.01-.20
Phosphorus, dissolved (P)	12	--	<.01-.060
Phosphorus, ortho phosphates dissolved (P)	6	--	<.001-.010
Carbon, organic dissolved (C)	18	3.8	1.4-8.2
Hardness, (as $CaCO_3$)	31	248	230-300
Hardness, (as noncarbonate, $CaCO_3$)	20	31.7	12-57
Calcium, dissolved (Ca)	30	55.4	48-63
Magnesium, dissolved (Mg)	30	28.4	21-35
Sodium, dissolved (Na)	30	5.2	4.2-6.7
Potassium, dissolved (K)	30	1.4	.50-4.1
Chloride, dissolved (Cl)	30	4.6	3.4-6.3
Sulfate, dissolved (SO_4)	30	32.3	20-43
Fluoride, dissolved (F)	23	.13	.10-.20
Silica, dissolved (SiO_2)	30	6.0	4.8-7.0

Table 14.—Summary of chemical analyses of streamflow in Crandall Canyon creek at station 09317919, water years 1979-84

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Milligrams per liter			
Arsenic, dissolved (As)	15	--	<1-2.0
Barium, dissolved (Ba)	5	--	<100
Boron, dissolved (B)	23	--	<10-60
Cadmium, dissolved (Cd)	9	--	<1
Chromium, dissolved (Cr)	12	--	<10-10
Copper, dissolved (Cu)	9	--	<2
Iron, dissolved (Fe)	23	--	<3-10
Lead, dissolved (Pb)	14	--	<1-15
Lithium, dissolved (Li)	11	--	<10-30
Manganese, dissolved (Mn)	23	--	<1-17
Mercury, dissolved (Hg)	9	--	<1-.9
Nickel, dissolved (Ni)	9	--	<1-10
Selenium, dissolved (Se)	15	--	<1-1
Strontium, dissolved (Sr)	11	195	180-220
Zinc, dissolved (Zn)	15	--	<3-82
Phenols	15	--	<1-25

[1]Fixed-end-point determined by titration in the field.

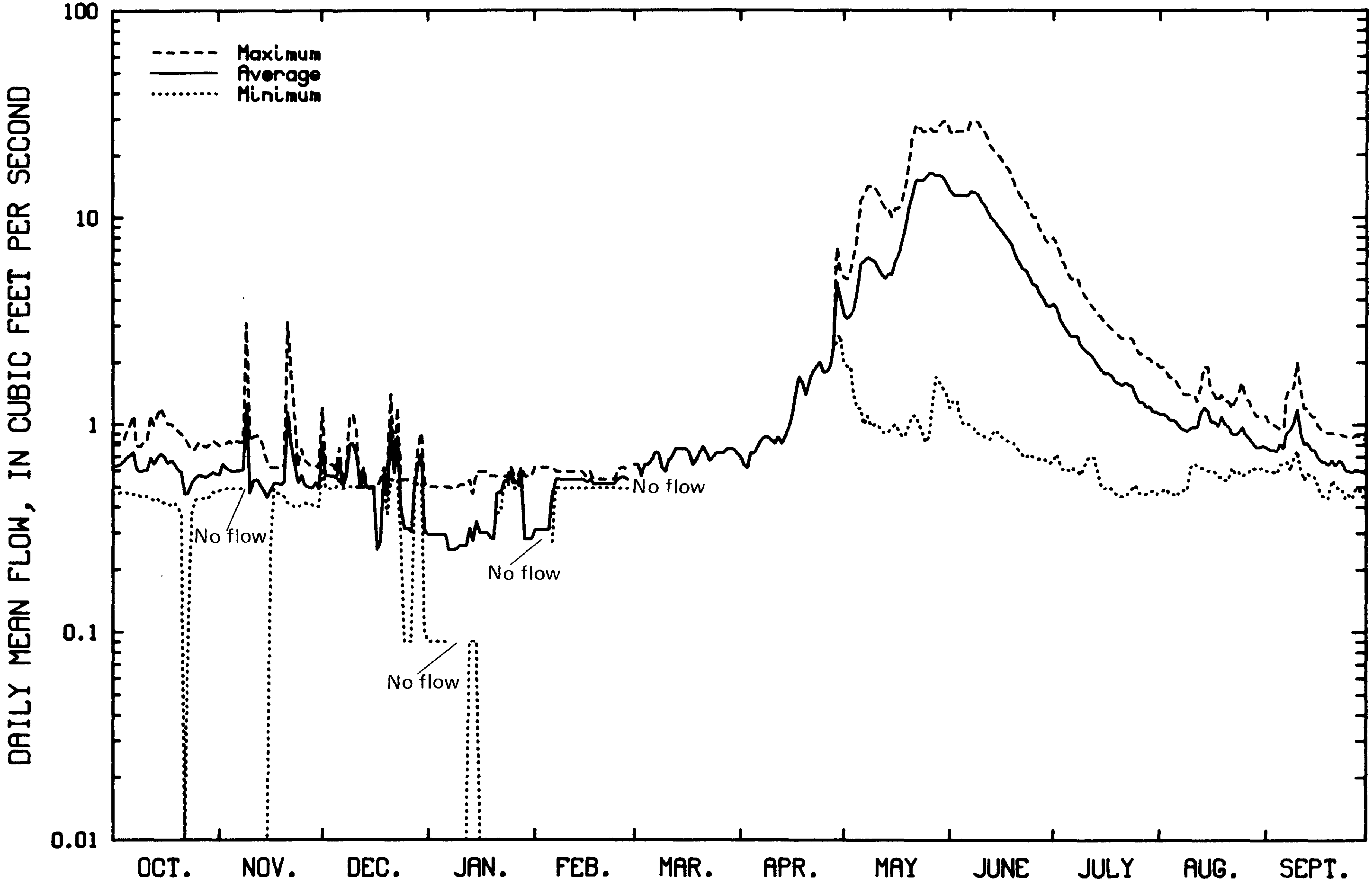

Figure 23.—Maximum, average, and minimum daily mean flow of Tie Fork at station 09317920, complete record for water year 1979 and seasonal record for water years 1980-81.

to 330 milligrams per liter, with a mean of 287 milligrams per liter (table 15). Calcium and magnesium were the dominant dissolved cations, and bicarbonate was the dominant dissolved anion. None of the trace elements were found in concentrations that exceeded the criteria established by the U.S. Environmental Protection Agency (1976) for drinking-water supplies. The maximum phenol concentration was 39 micrograms per liter, compared to a criterion of 1 microgram per liter.

The suspended-sediment concentrations in 13 streamflow samples collected at station 09317920 during the 1979-81 water years ranged from 2 milligrams per liter on January 26, 1981, to 648 milligrams per liter on May 25, 1980. The calculated instantaneous suspended-sediment loads at the station ranged from 0.12 to 0.17 tons per day during water year 1979, 0.03 to 45 tons per day during water year 1980, and less than 0.01 to 0.12 tons per day during water year 1981. Coal was 0.5 percent of the stream-bottom sediments sampled at the station.

Two samples of benthic invertebrates collected at station 09317920 during the 1980 water year had fairly good diversity (U.S. Geological Survey, 1981, p. 310), reflecting an apparently unpolluted stream-bottom environment at the site during sampling. Five phytoplankton samples collected during water year 1981 had a fairly uniform distribution of green algae (U.S. Geological Survey, 1982, p. 318).

Station 09317997 was operated continuously during water years 1980 and 1981 (table 1). The annual mean flow ranged from 63 cubic feet per second during water year 1981 to 112 cubic feet per second in water year 1980 (table 3). Maximum, minimum, and average daily mean flow recorded at the station is shown in figure 24.

Base-flow measurements in Huntington Creek were made upstream from station 09318000 during August 1978-August 1981. The results of those measurements, which are related to geology in figure 25, indicate negligible gain or loss of flow as the stream crosses the Mancos Shale or the Star Point Sandstone. Discharge from the Deer Creek Mine did not reach the stream during 1979 (Lines and Plantz 1981, p. 35); therefore, it was assumed not to have done so during the entire period of base-flow measurements.

The chemical analyses of 25 streamflow samples collected from Huntington Creek at station 09317997 during October 1979-September 1981 are summarized in table 16. Dissolved-solids concentrations ranged from 160 to 270 milligrams per liter, with a mean of 218 milligrams per liter. The dominant cation was calcium and the dominant anion was bicarbonate. None of the trace elements that were analyzed were found in concentrations that exceeded the criteria established by the U.S. Environmental Protection Agency (1976) for drinking-water supplies. The maximum phenol concentration was 14 micrograms per liter, compared to a criterion of 1 microgram per liter.

Suspended-sediment data were collected at station 09317997 during the 1980 and 1981 water years. Suspended-sediment concentrations in 23 streamflow samples collected ranged from 5 to 1,830 milligrams per liter. The calculated instantaneous suspended-sediment loads at the station ranged from 2.2 to 1,830 tons per day during the 1980 water year, and from 0.39 to 529 tons per day

Table 15.—Summary of chemical analyses of streamflow in Tie Fork at station 09317920, water years 1979-81

[<indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	22	2.4	0.38-26
Water temperature (degrees Celsius)	22	7.9	.0-14.0
Specific conductance (microsiemens per centimeter at 25^{o} Celsius)	22	488	425-580
pH (units)	22	—	8.2-8.7
Sodium-adsorption ratio	22	0.08	.0-.1
Milligrams per liter			
Dissolved solids, sum of constituents	22	287	240-330
Oxygen, dissolved (O_2)	22	9.3	7.9-11.4
Carbon dioxide, dissolved (CO_2)	21	1.5	.8-3.3
Alkalinity ($CaCO_3$)[1]	21	234	205-280
Bicarbonate (HCO_3)[1]	21	262	230-340
Carbonate (CO_3)[1]	21	7.0	.0-16
Nitrogen, dissolved (N)	7	.74	.32-2.0
Nitrogen, organic dissolved (N)	6	.32	.12-.52
Nitrogen, ammonia dissolved (N)	6	--	<.01-.06
Nitrogen, nitrite dissolved (N)	6	--	<.01-.01
Nitrogen, nitrate dissolved (N)	6	.37	.09-1.4
Nitrogen, nitrite + nitrate dissolved (N)	9	.30	.09-1.4
Phosphorus, dissolved (P)	3	.02	.01-.02
Phosphorus, ortho phosphates dissolved (P)	6	--	<.001-.040
Carbon, organic dissolved (C)	9	7.2	1.2-21
Hardness, (as $CaCO_3$)	22	266	220-310
Hardness, (as noncarbonate, $CaCO_3$)	21	31.9	8.0-56
Calcium, dissolved (Ca)	22	57	49-70
Magnesium, dissolved (Mg)	22	30	18-36
Sodium, dissolved (Na)	22	4.2	3.0-5.3
Potassium, dissolved (K)	22	1.7	1.0-4.6
Chloride, dissolved (Cl)	22	4.9	3.6-9.8
Sulfate, dissolved (SO_4)	22	34	18-41
Fluoride, dissolved (F)	14	.1	.1-.2
Silica, dissolved (SiO_2)	22	6.2	4.8-7.0

Table 15.—Summary of chemical analyses of streamflow in Tie Fork at station 09317920, water years 1979-81—Continued

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Milligrams per liter			
Arsenic, dissolved (As)	9	—	<1-2.0
Barium, dissolved (Ba)	2	--	<100
Boron, dissolved (B)	14	—	<10-60
Cadmium, dissolved (Cd)	3	--	<1
Chromium, dissolved (Cr)	7	—	<20
Copper, dissolved (Cu)	3	--	<2-2
Iron, dissolved (Fe)	14	—	<10-40
Lead, dissolved (Pb)	8	--	<1-19
Lithium, dissolved (Li)	8	—	<10-30
Manganese, dissolved (Mn)	14	--	<10
Mercury, dissolved (Hg)	3	—	.10
Nickel, dissolved (Ni)	3	--	.0-<1
Selenium, dissolved (Se)	8	—	<1-1
Strontium, dissolved (Sr)	8	232	200-260
Zinc, dissolved (Zn)	9	—	<3-50
Phenols	9	11	1-39

[1]Fixed-end-point determined by titration in the field.

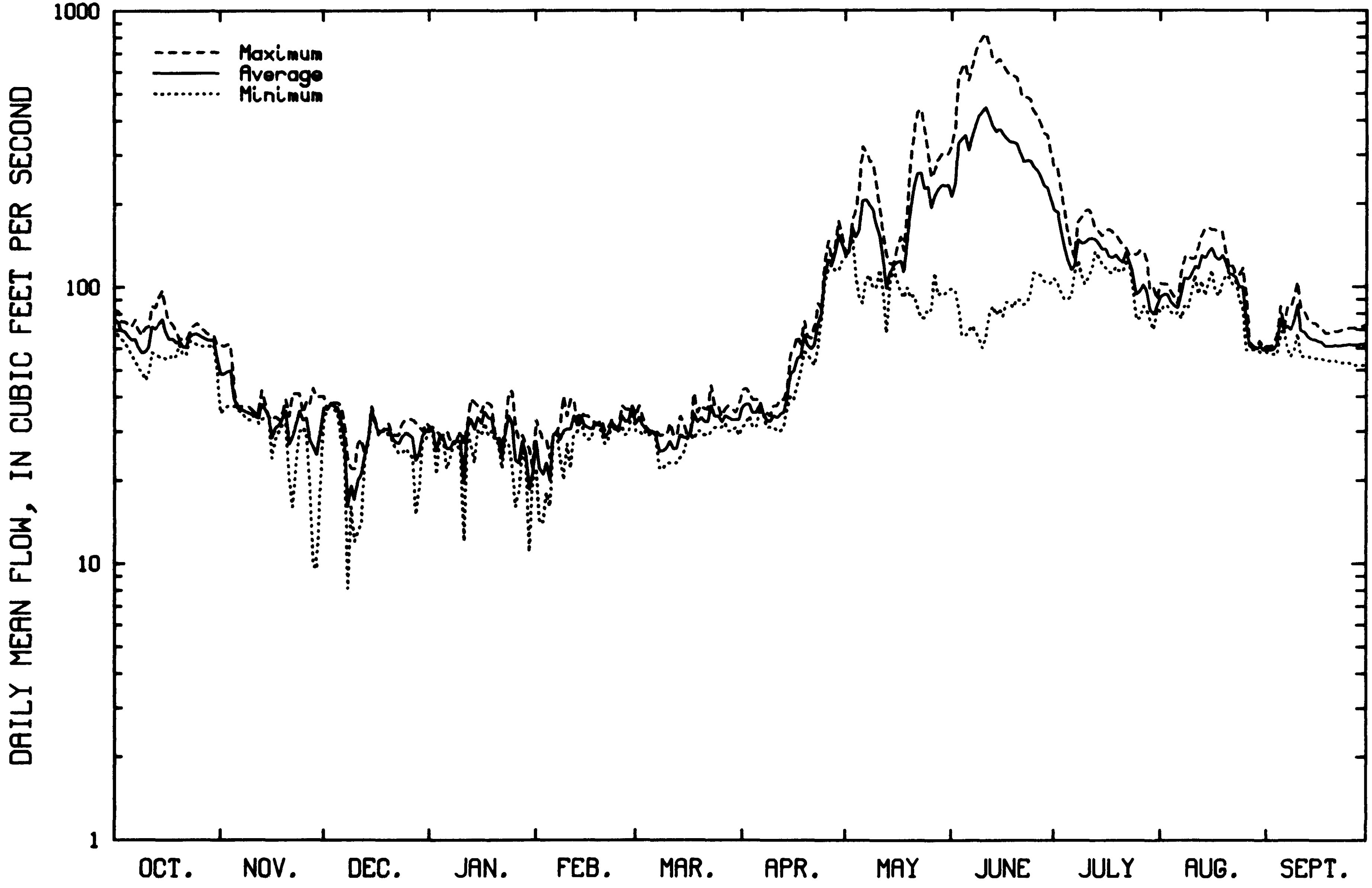

Figure 24.—Maximum, average, and minimum daily mean flow of Huntington Creek at station 09317997, water years 1980-81.

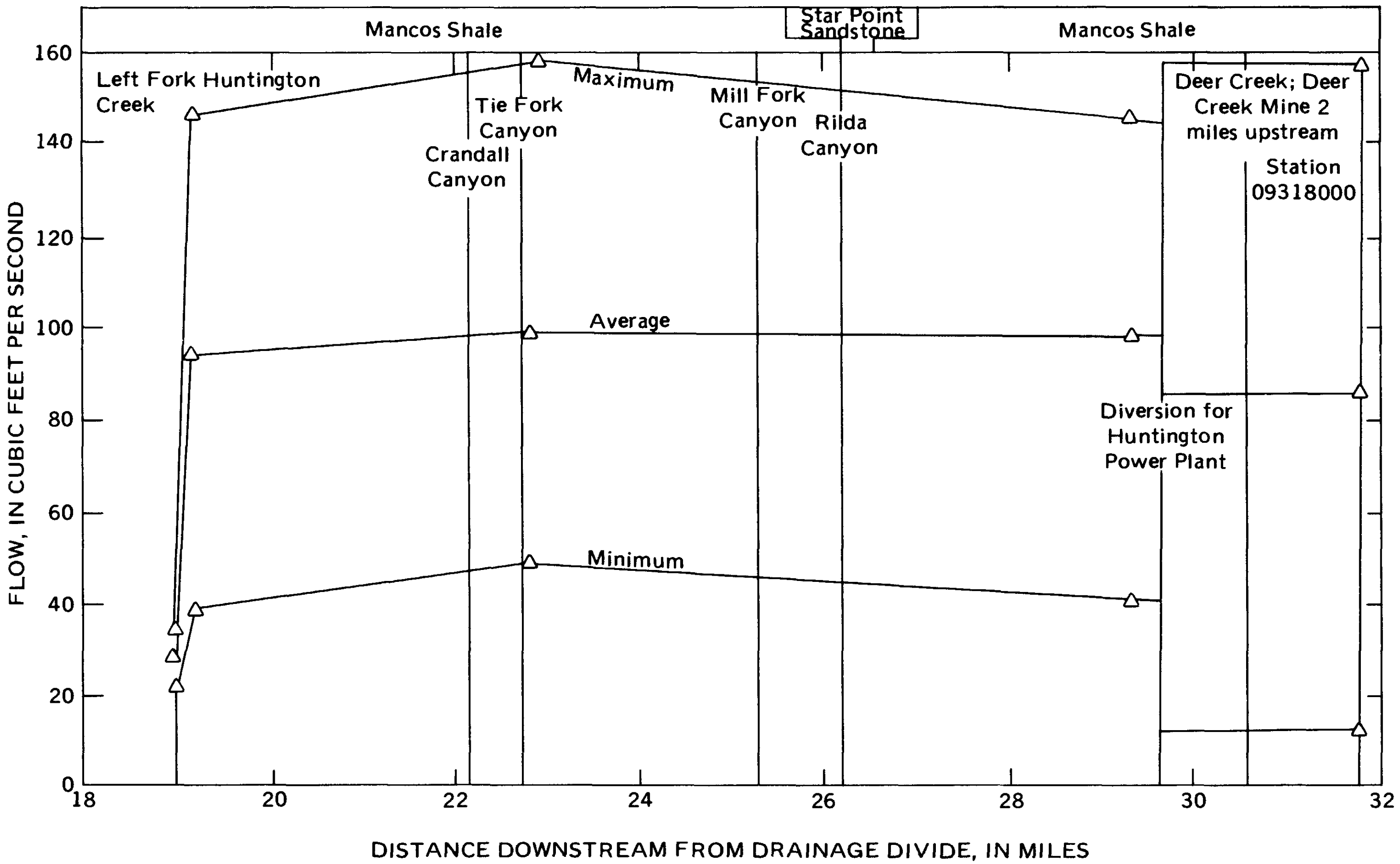

Figure 25.—Base flow of Huntington Creek as related to geology (based on 8 measurements made at each site from August 1978 to August 1981; the maximum value at station 09318000 reflects overflow from a small storage pond).

Table 16.—Summary of chemical analyses of streamflow in Huntington Creek at station 09317997, water years 1980-81

[<indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	25	87	16-374
Water temperature (degrees Celsius)	25	7.1	0.0-16.5
Specific conductance (microsiemens per centimeter at 25^{o} Celsius)	25	379	290-470
pH (units)	25	--	8.1-8.7
Sodium-adsorption ratio	25	0.1	.0-0.2
Milligrams per liter			
Dissolved solids, sum of constituents	25	218	160-270
Oxygen, dissolved (O_2)	25	9.8	7.7-11.6
Carbon dioxide, dissolved (CO_2)	24	1.4	.5-3.2
Alkalinity ($CaCO_3$)	24	188	150-230
Bicarbonate (HCO_3)[1]	24	221	170-270
Carbonate (CO_3)[1]	24	--	.0-8.0
Nitrogen, dissolved (N)	11	.62	.30-1.0
Nitrogen, organic dissolved (N)	7	.42	.27-.76
Nitrogen, ammonia dissolved (N)	7	--	<.01-.030
Nitrogen, nitrite dissolved (N)	7	--	<.01-.010
Nitrogen, nitrate dissolved (N)	7	--	<.05-.30
Nitrogen, nitrite + nitrate dissolved (N)	11	--	<.01-.30
Phosphorus, dissolved (P)	4	--	<.01-.30
Phosphorus, ortho phosphates dissolved (P)	7	--	<.001-.010
Carbon, organic dissolved (C)	11	9.3	2.2-36.0
Hardness, (as $CaCO_3$)	25	193	110-250
Hardness, (as noncarbonate, $CaCO_3$)	24	14.0	.0-34.0
Calcium, dissolved (Ca)	25	50	38-59
Magnesium, dissolved (Mg)	25	17	11-24
Sodium, dissolved (Na)	25	4.4	2.5-7.3
Potassium, dissolved (K)	25	1.2	.6-1.5
Chloride, dissolved (Cl)	25	4.3	1.7-8.2
Sulfate, dissolved (SO_4)	25	--	<1.0-39.0
Fluoride, dissolved (F)	20	.1	.1-.2
Silica, dissolved (SiO_2)	25	3.8	2.5-6.0

Table 16.—Summary of chemical analyses of streamflow in Huntington Creek at station 09317997, water years 1980-81—Continued

Milligrams per liter

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Arsenic, dissolved (As)	9	—	<1.0-2.0
Barium, dissolved (Ba)	2	—	<100-200
Boron, dissolved (B)	20	—	<10-160
Cadmium, dissolved (Cd)	2	—	<1
Chromium, dissolved (Cr)	9	—	<10-20
Copper, dissolved (Cu)	2	—	1-1
Iron, dissolved (Fe)	20	—	<10-110
Lead, dissolved (Pb)	9	—	<1.0-1
Lithium, dissolved (Li)	9	—	<10-30
Manganese, dissolved (Mn)	20	7.1	4.0-32.0
Mercury, dissolved (Hg)	2	—	<.1
Nickel, dissolved (Ni)	2	1.5	1.0-2.0
Selenium, dissolved (Se)	9	—	<1-1.0
Strontium, dissolved (Sr)	9	133	110-170
Zinc, dissolved (Zn)	9	—	<3-7.0
Phenols	11	—	<1-14

[1]Fixed-end-point determined by titration in the field.

during the 1981 water year. Coal was 1.2 percent of the stream-bottom samples.

Six samples of benthic invertebrates collected at station 09317997 during the 1980 and 1981 water years (U.S. Geological Survey, 1981, p. 315; 1982, p. 326), and the benthic invertebrates collected at station 09318000 during the 1979 water year (Lines and Plantz, 1981, p. 39), all apparently reflect the excellent chemical quality of water in Huntington Creek (table 16). Three samples of phytoplankton were collected at station 09317997 during water years 1980 and 1981. Green algae were well distributed in most early summer samples, but blue-green algae was more dominant in the August (low-flow) samples.

Cottonwood Creek

Cottonwood Creek originates on the Flagstaff Limestone at an altitude of about 10,500 feet on the Wasatch Plateau. It has cut a deep, narrow canyon through the Cretaceous formations shown in figure 1, and where it emerges from the canyon into Castle Valley it is flowing over the Mancos Shale at an altitude of about 6,000 feet. The lower reach of the creek receives most of its flow by releases from Joes Valley Reservoir through Straight Canyon. Station 09324200 (pl. 1, table 1) is upstream from the confluence with Straight Canyon, but it is several hundred feet downstream from the Trail Mountain Mine (pl. 1). At the station, Cottonwood Creek is flowing on the Star Point Sandstone at an altitude of 6,940 feet.

The Trail Mountain Mine was placed in operation several years before station 09324200 was installed, and the land leveling required for mine-portal facilities left considerable loose silt and soil adjacent to Cottonwood Creek. The mine was in operation during the monitoring period, but apparently it did not discharge water into Cottonwood Creek. Some workings of the Deer Creek Mine (pl. 1) advanced from the Huntington Creek basin into the Cottonwood Creek basin during the monitoring period.

Data collected at station 09324200 during the 1979-81 water years (table 1) supplement streamflow and water-quality data collected at the long-term gaging station 09324500, which is about 3 miles downstream from the confluence with Straight Canyon (pl. 1). (See ReMillard and others, 1985, p. 185.) The mean flow recorded at station 09324200 during the 1979 water year was 0.87 cubic feet per second (table 1). This is less than 1 percent of the corresponding flow recorded at station 09324500. The maximum, minimum, and average daily mean flow of Cottonwood Creek at station 09324200 is shown in figure 26. Much of the flow is from late May to early July, chiefly in response to snowmelt on the Wasatch Plateau. The maximum peak flow recorded was only 22.0 cubic feet per second on June 5, 1980, and the minimum was zero (table 3).

A series of base-flow measurements (generally two sets per year) were made along Cottonwood Creek upstream from station 09324200 during August 1978-August 1981. The results of those measurements are related to geology in figure 27. The stream seems to gain some flow where it crosses the Blackhawk Formation. The minimum flow line, however, indicates some loss from the stream.

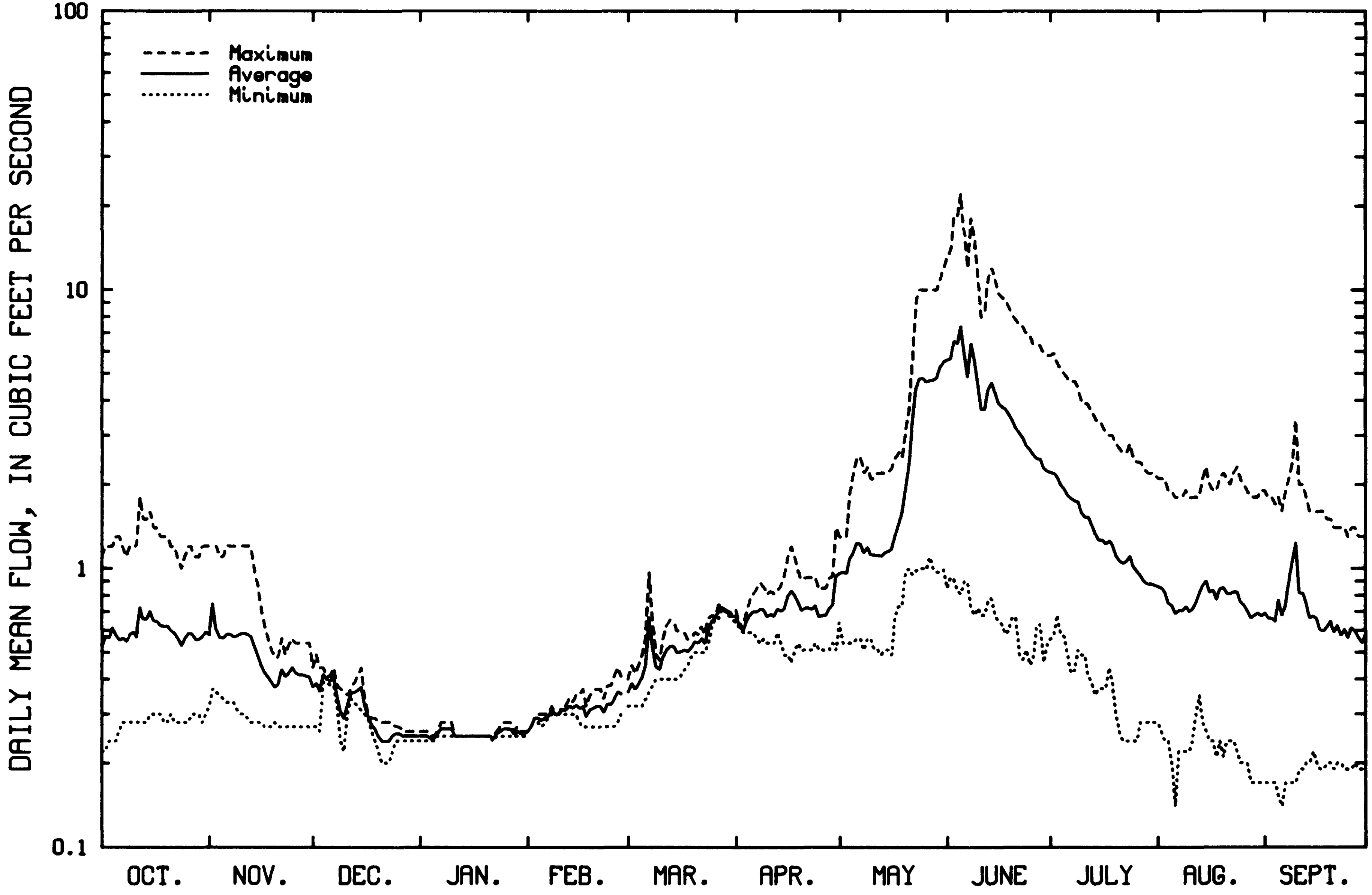

Figure 26.—Maximum, average, and minimum daily mean flow of Cottonwood Creek at station 09324200, complete record for water year 1979 and seasonal record for water years 1980-81.

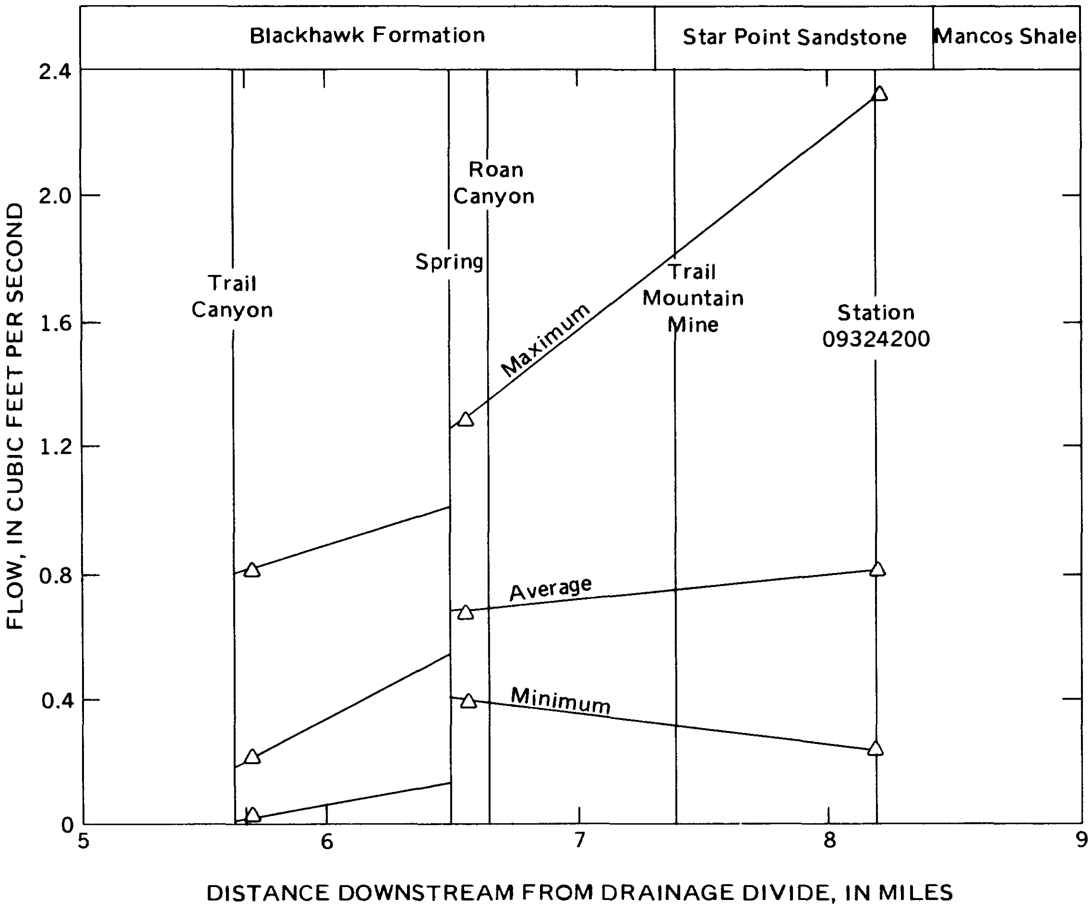

Figure 27.—Base flow of Cottonwood Creek as related to geology (based on 7 measurements made at each site from August 1978 to August 1981).

Chemical analyses of 22 streamflow samples collected at station 09324200 during the 1979-81 water years are summarized in table 17. The dissolved-solids concentrations ranged from 290 to 460 milligrams per liter, with a mean of 350 milligrams per liter. Magnesium and calcium were the dominant cations while bicarbonate was the dominant anion. Of the trace elements that were analyzed, lead and manganese were found in concentrations that exceed the criteria established by the U.S. Environmental Protection Agency (1976), for drinking-water supplies. The maximum concentration of lead and manganese was 130 and 110 micrograms per liter, compared to the criteria of 50 micrograms per liter for both ions. The maximum concentration of phenol was 13 micrograms per liter, compared to a criterion of 1 microgram per liter.

Suspended-sediment data were collected at station 09324200 during the 1979 water year, and according to Lines and Plantz (1981, p. 44) the instantaneous suspended-sediment loads ranged from 0.01 to 0.20 tons per day. The suspended-sediment concentrations in 13 streamflow samples collected during the 1980 and 1981 water years ranged from 4 milligrams per liter in June and August 1981 to 1,270 milligrams per liter on November 10, 1980. Calculated instantaneous suspended-sediment loads ranged from 0.21 to 32 tons per day during the 1980 water year, and from less than 0.01 to 0.51 tons per day during the 1981 water year. Stream-bottom sediments consisted of as much as 4.4 percent coal.

Two samples of benthic invertebrates were collected at station 09324200 during the 1980 water year (U.S. Geological Survey, 1981, p. 323) and five samples of phytoplankton were collected during the 1981 water year (U.S. Geological Survey, 1982, p. 335). The benthic invertebrates collected during water year 1980 had good diversity, as did the two samples collected during water year 1979 (Lines and Plantz, 1981, p. 44). The phytoplankton samples contained a uniform distribution of green algae, but some blue-green algae was observed in August and September (low flow) samples.

DIRTY DEVIL RIVER BASIN

Quitchupah Creek, Convulsion Canyon Creek, and Christiansen Wash

Quitchupah Creek originates on the southern part of the Wasatch Plateau at an altitude of about 10,800 feet. It heads on the Flagstaff Limestone and has cut a canyon through the Cretaceous formations shown in figure 1. Station 09331900 (pl. 1, table 1) is on the coal-bearing Ferron Sandstone Member of the Mancos Shale at an altitude of 5,900 feet.

Convulsion Canyon creek and Christiansen Wash are tributaries of Quitchupah Creek. Convulsion Canyon creek originates on the Flagstaff Limestone at an altitude of about 9,000 feet. It cuts through the coal-bearing Blackhawk Formation and joins Quitchupah Creek at an altitude of about 6,600 feet. Station 09331850 on Convulsion Canyon creek (pl. 1, table 1) is at an altitude of 7,120 feet. Christiansen Wash originates on the Castlegate Sandstone at an altitude of about 8,800 feet. It cuts through the older Cretaceous formations shown in figure 1 and joins Quitchupah Creek at an altitude of about 5,900 feet. Station 09331950 on Christiansen Wash (pl. 1, table 1) is upstream from the confluence with Quitchupah Creek at an altitude

Table 17.—Summary of chemical analyses of streamflow in Cottonwood Creek at station 09324200, water years 1979-81

[< indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	22	1.6	0.20-11.0
Water temperature (degrees Celsius)	22	11.7	.0-21.5
Specific conductance (microsiemens per centimeter at 25^{o} Celsius)	22	573	500-660
pH (units)	22	--	8.3-8.9
Sodium-adsorption ratio	22	0.5	.3-0.5
Milligrams per liter			
Dissolved solids, sum of constituents	22	350	290-460
Oxygen, dissolved (O_2)	22	8.8	6.8-11.6
Carbon dioxide, dissolved (CO_2)	21	1.3	.6-3.3
Alkalinity ($CaCO_3$)	21	262	197-440
Bicarbonate (HCO_3)[1]	21	299	240-520
Carbonate (CO_3)[1]	21	11.6	.0-24
Nitrogen, dissolved (N)	7	.72	.22-1.10
Nitrogen, organic dissolved (N)	6	.34	.13-.68
Nitrogen, ammonia dissolved (N)	6	--	<.01-.070
Nitrogen, nitrite dissolved (N)	6	--	<.01-.01
Nitrogen, nitrate dissolved (N)	6	.24	.08-.34
Nitrogen, nitrite + nitrate dissolved (N)	9	.28	.08-.52
Phosphorus, dissolved (P)	3	.01	.01-.02
Phosphorus, ortho phosphates dissolved (P)	6	--	<.001-.040
Carbon, organic dissolved (C)	9	6.2	1.5-19
Hardness, (as $CaCO_3$)	22	287	250-340
Hardness, (as noncarbonate, $CaCO_3$)	21	32.5	.0-61
Calcium, dissolved (Ca)	22	48	34-67
Magnesium, dissolved (Mg)	22	40	31-47
Sodium, dissolved (Na)	22	17	13-22
Potassium, dissolved (K)	22	2.3	.8-6.1
Chloride, dissolved (Cl)	22	11.6	8.5-19
Sulfate, dissolved (SO_4)	22	57	40-80
Fluoride, dissolved (F)	14	.1	.1-.2
Silica, dissolved (SiO_2)	22	6.8	5.8-7.2

Table 17.—Summary of chemical analyses of streamflow in Cottonwood Creek at station 09324200, water years 1979-81—Continued

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Milligrams per liter			
Arsenic, dissolved (As)	9	--	<1-2.0
Barium, dissolved (Ba)	2	--	<100
Boron, dissolved (B)	14	48	20-200
Cadmium, dissolved (Cd)	3	--	<1
Chromium, dissolved (Cr)	6	--	<10-10
Copper, dissolved (Cu)	3	--	<2-2.0
Iron, dissolved (Fe)	14	--	<10-30
Lead, dissolved (Pb)	8	--	<1-130
Lithium, dissolved (Li)	8	--	<10-40
Manganese, dissolved (Mn)	14	--	<2-20
Mercury, dissolved (Hg)	3	--	<.1
Nickel, dissolved (Ni)	3	--	<1
Selenium, dissolved (Se)	9	--	1
Strontium, dissolved (Sr)	8	342	300-390
Zinc, dissolved (Zn)	9	--	<3-10
Phenols	9	--	<1-13

[1]Fixed-end-point determined by titration in the field.

of 5,920 feet. The confluence of Convulsion Canyon creek and Christiansen Wash with Quitchupah Creek are on the coal-bearing Ferron Sandstone Member of the Mancos Shale.

More than 6,000 acres of Federal coal have been leased in the Quitchupah Creek basin upstream from stations 09331850, 09331900, and 09331950 (pl. 1). The Convulsion Canyon Mine, upstream from station 09331850, was producing coal from the Blackhawk Formation during the complete monitoring period at that station. The Emery Mine was producing coal from the Ferron Sandstone Member during the monitoring periods at stations 09331900 and 09331950.

According to Waddell and others (1981, table 8), as much as 0.2 cubic feet per second of unconsummed mine water containing about 275 milligrams per liter of dissolved-solids has been discharged intermittently from the Convulsion Canyon Mine to Convulsion Canyon creek. The dominant ions in water from the Convulsion Canyon Mine were magnesium, calcium, and bicarbonate.

According to Lines and Plantz (1981, p. 47), an average of 0.7 cubic feet per second of unconsummed mine water was discharged in 1979 from the Emery Mine to Quitchupah Creek. The water discharged from the Emery Mine is of poor chemical quality. Three samples collected during 1976 and 1979 showed a range of dissolved solids from 3,040-5,100 milligrams per liter (Lines and Plantz, 1981, p. 47). The predominant dissolved ions were sodium and sulfate.

Seasonal records were collected at station 09331850 on Convulsion Canyon creek, during water years 1981-84, and the maximum, minimum, and average daily mean flows are shown in figure 28. Most of the flow occurs during the April-June period of snowmelt. The maximum peak flow recorded at the station was 34.0 cubic feet per second on July 30, 1984, which resulted from a thunderstorm.

The dissolved-solids concentrations in 14 streamflow samples collected at station 09331850 ranged from 320 to 860 milligrams per liter, with a mean of 509 milligrams per liter (table 18). Calcium, magnesium, and bicarbonate were the dominant ions in most samples. Of the trace elements that were analyzed, only manganese was found in concentrations that exceed the criteria established by the U.S. Environmental Protection Agency (1976) for drinking-water supplies. The maximum concentration of manganese was 61 micrograms per liter, compared to a criterion of 50 micrograms per liter. The maximum concentration of boron was 790 micrograms per liter, which exceeded the criterion of 750 micrograms per liter for long-term irrigation on sensitive crops (U.S. Environmental Protection Agency, 1976, p. 25). The maximum concentration of phenol was 9 micrograms per liter, compared to a criterion of 1 microgram per liter.

A small quantity of sediment data were collected at station 09331850. A streamflow sample collected on October 22, 1980 had a suspended-sediment concentration of 17 milligrams per liter, and another sample collected on September 7, 1981, had a suspended-sediment concentration of 180 milligrams per liter. Calculated instantaneous suspended-sediment loads at station 09331850 during water year 1981 ranged from less than 0.01 to 0.73 tons per day. No bottom-sediment samples were collected.

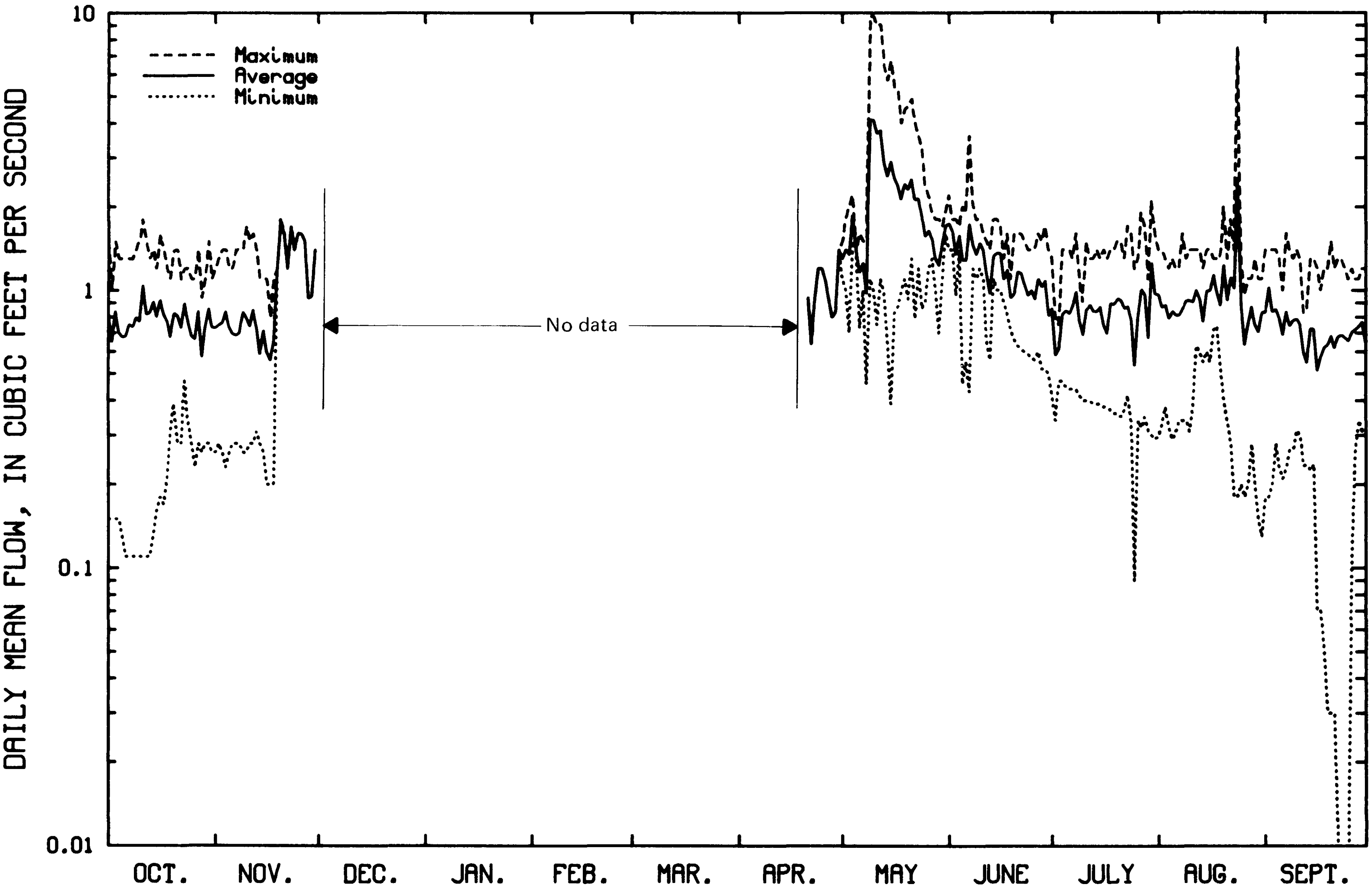

Figure 28.—Maximum, average, and minimum daily mean flow of Convulsion Canyon creek at station 09331850, seasonal record for water years 1981-84.

Table 18.—Summary of chemical analyses of streamflow in Convulsion Canyon creek at station 09331850, water years 1981-84

[< indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	14	0.86	0.15-1.7
Water temperature (degrees Celsius)	14	12.5	4.5-16.0
Specific conductance (microsiemens per centimeter at 25° Celsius)	14	395	680-1,330
pH (units)	14	--	8.1-8.6
Sodium-adsorption ratio	14	.71	.50-1.0
Milligrams per liter			
Dissolved solids, sum of constituents	14	509	320-860
Oxygen, dissolved (O_2)	14	8.0	7.2-9.4
Carbon dioxide, dissolved (CO_2)	7	2.3	1.4-4.0
Alkalinity ($CaCO_3$)	7	257	220-330
Bicarbonate (HCO_3)[1]	7	307	260-400
Carbonate (CO_3)[1]	7	3.3	.0-9.0
Nitrogen, dissolved (N)	6	.56	.37-0.76
Nitrogen, organic dissolved (N)	-	--	--
Nitrogen, ammonia dissolved (N)	-	--	--
Nitrogen, nitrite dissolved (N)	-	--	--
Nitrogen, nitrate dissolved (N)	-	--	--
Nitrogen, nitrite + nitrate dissolved (N)	9	--	.03-1.1
Phosphorus, dissolved (P)	9	--	<.01-.080
Phosphorus, ortho phosphates dissolved (P)	-	--	--
Carbon, organic dissolved (C)	9	4.5	1.3-8.4
Hardness, (as $CaCO_3$)	14	428	300-640
Hardness, (as noncarbonate, $CaCO_3$)	7	103	88-150
Calcium, dissolved (Ca)	14	81.7	58-110
Magnesium, dissolved (Mg)	14	54.1	38-90
Sodium, dissolved (Na)	14	33.6	23-51
Potassium, dissolved (K)	14	3.6	2.0-6.6
Chloride, dissolved (Cl)	14	35.5	12-97
Sulfate, dissolved (SO_4)	14	166	100-280
Fluoride, dissolved (F)	14	.26	.20-.50
Silica, dissolved (SiO_2)	14	11.5	10-13

Table 18.—Summary of chemical analyses of streamflow in Convulsion Canyon creek at station 09331850, water years 1981-84—Continued

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Milligrams per liter			
Arsenic, dissolved (As)	7	—	<1-3.0
Barium, dissolved (Ba)	3	--	<100
Boron, dissolved (B)	14	249	100-790
Cadmium, dissolved (Cd)	7	--	<3
Chromium, dissolved (Cr)	7	—	<10-10
Copper, dissolved (Cu)	7	--	<2-2
Iron, dissolved (Fe)	14	—	<10-27
Lead, dissolved (Pb)	7	--	<1-3
Lithium, dissolved (Li)	3	31.3	20-44
Manganese, dissolved (Mn)	14	21.8	9.0-61
Mercury, dissolved (Hg)	7	—	<.1-.4
Nickel, dissolved (Ni)	7	1.7	1.0-2.0
Selenium, dissolved (Se)	7	—	<1-4.0
Strontium, dissolved (Sr)	3	527	500-550
Zinc, dissolved (Zn)	7	—	<3-30
Phenols	6	3.2	1.0-9.0

[1]Fixed-end-point determined by titration in the field.

Two of five samples of phytoplankton collected at station 09331850 during water year 1981 had large counts of blue-green algae (U.S. Geological Survey, 1982, p. 361). The samples were collected during August and September, and they apparently represent low-flow conditions.

Station 09331900 on Quitchupah Creek was operated continuously during water years 1979-81. The annual mean flow ranged from 6.73 cubic feet per second during water year 1979 to 10.8 cubic feet per second during water year 1980 (table 3). The maximum, minimum, and average daily mean flow shown in figure 29 indicate that the flow is relatively uniform throughout the year. This reflects a significant ground-water component of the total flow in Quitchupah Creek. Peaks during April-June represent snowmelt runoff, and peaks during July-November represent storm runoff from thunderstorms. The maximum peak flow recorded at station 09331900 during water years 1979-81 was 2,590 cubic feet per second on September 8, 1981 (table 3). That flow resulted from a thunderstorm.

Base-flow measurements in Quitchupah Creek during water years 1979-81 are related to geology in figure 30. The average, maximum, and minimum values show an increase in the base flow of Quitchupah Creek downstream from U.S. Highway 10. According to Lines and Plantz (1981, p. 47), the increase in flow is chiefly due to the return of water diverted for irrigation. The return flow results in an addition to the dissolved-solids concentrations, consisting mainly of sodium and sulfate.

The dissolved-solids concentrations in 39 streamflow samples collected from Quitchupah Creek at station 09331900 during water years 1979-81 ranged from 580 to 4,300 milligrams per liter, with a mean of 1,760 milligrams per liter (table 19). The smaller concentrations probably represent runoff from storms and snowmelt, whereas the larger concentrations represent mine discharge and irrigation return flow. Sodium and sulfate were the dominant ions in virtually all the samples regardless of the dissolved-solids concentrations. Strontium was found in concentrations as large as 4,800 micrograms per liter; however, none of the trace elements that were analyzed exceeded the criteria established by the U.S. Environmental Protection Agency (1976) for drinking-water supplies. The maximum phenol concentration was 120 micrograms per liter, compared to a criterion of 1 microgram per liter.

Quitchupah Creek transports considerable quantities of sediment during storms and periods of snowmelt. The suspended-sediment concentrations in 35 streamflow samples collected at station 09331900 during water years 1979-81 ranged from 150 milligrams per liter on December 13, 1978 to 30,200 milligrams per liter on March 6, 1979. Instantaneous suspended-sediment loads calculated for the station ranged from 1.9 to 4,120 tons per day during water year 1979, 5.4 to 322 tons per day during water year 1980, and 2.3 to 778 tons per day during water year 1981. Coal was 0.3 percent of the stream-bottom sediments.

The two samples of benthic invertebrates collected at station 09331900 during the 1980 water year had poor diversity (U.S. Geological Survey, 1981, p. 354). The four samples of phytoplankton that were collected during water year 1981 (U.S. Geological Survey, 1982, p. 367) had good representations of both green and blue-green algae.

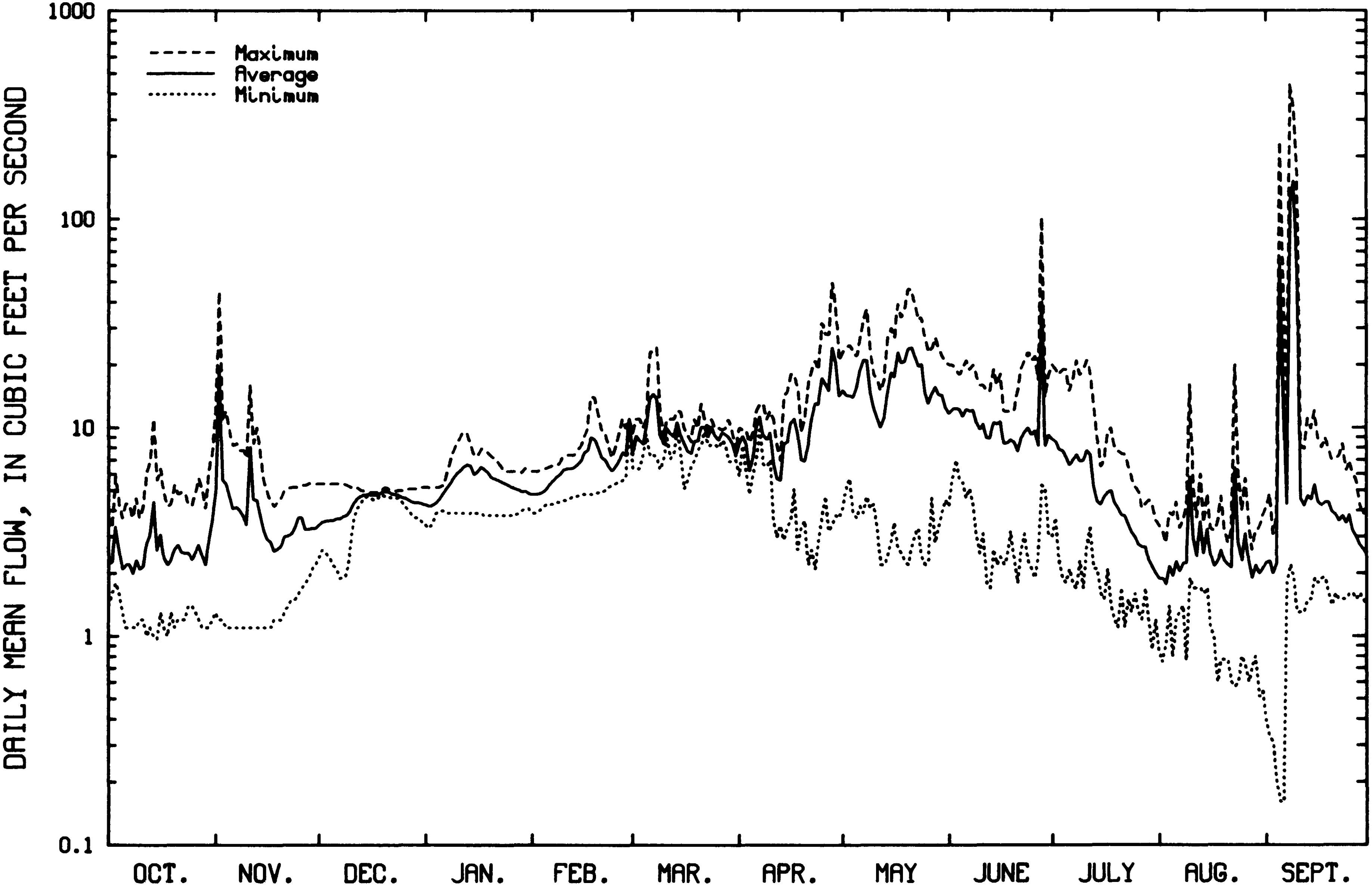

Figure 29.—Maximum, average, and minimum daily mean flow of Quitchupah Creek at station 09331900, water years 1979-81.

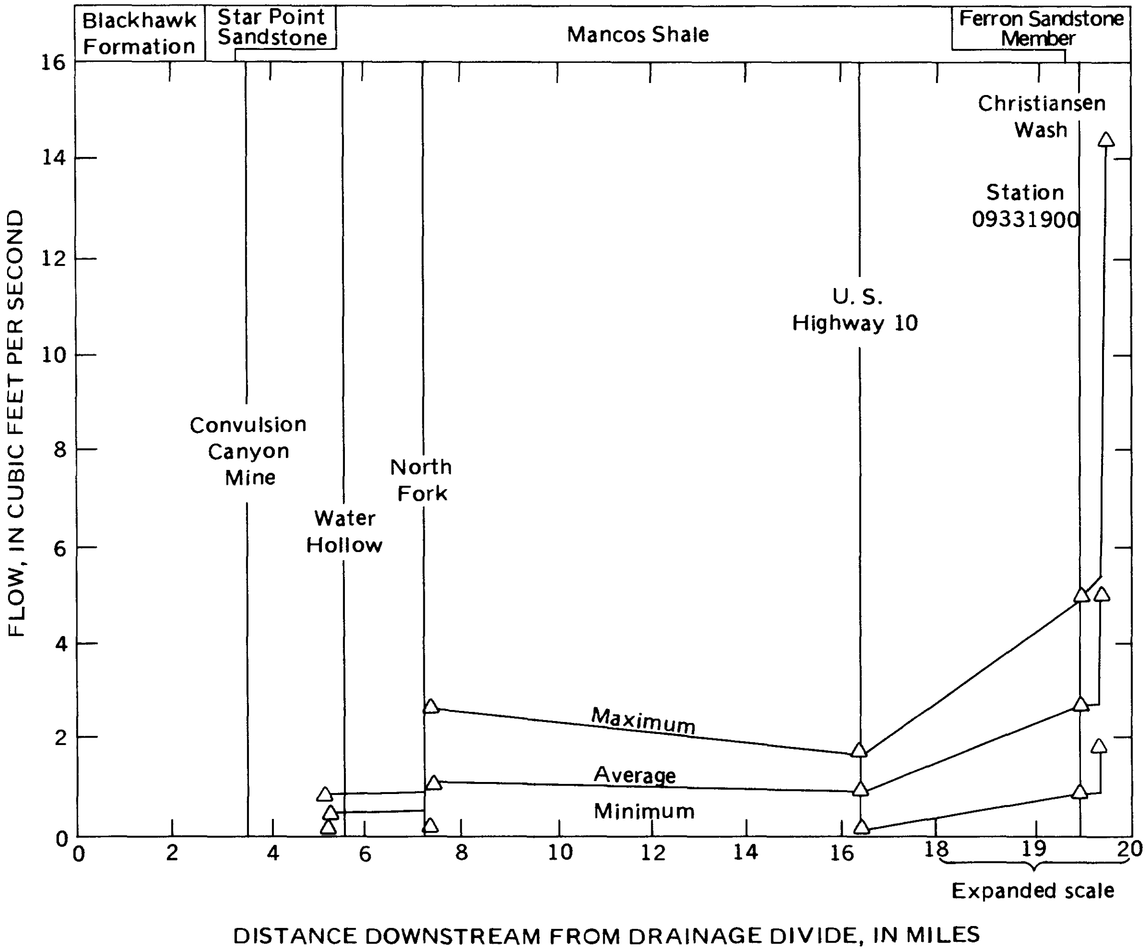

Figure 30.—Base flow of Quitchupah Creek as related to geology (based on 7 measurements made from August 1978 to October 1981).

Table 19.—Summary of chemical analyses of streamflow in Quitchupah Creek at station 09331900, water years 1979-81

[< indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	39	6.7	0.97-25
Water temperature (degrees Celsius)	39	11.0	.0-26.0
Specific conductance (microsiemens per centimeter at 25° Celsius)	39	2,280	890-5,500
pH (units)	39	--	8.1-8.8
Sodium-adsorption ratio	39	5.4	2.0-13.0
Milligrams per liter			
Dissolved solids, sum of constituents	39	1,760	580-4,300
Oxygen, dissolved (O_2)	39	9.3	6.3-11.8
Carbon dioxide, dissolved (CO_2)	38	3.0	.7-15
Alkalinity ($CaCO_3$)	38	341	212-960
Bicarbonate (HCO_3)[1]	38	407	250-1,180
Carbonate (CO_3)[1]	38	3.9	.0-14
Nitrogen, dissolved (N)	11	2.1	1.0-4.7
Nitrogen, organic dissolved (N)	9	0.44	.14-0.78
Nitrogen, ammonia dissolved (N)	9	--	<.01-.060
Nitrogen, nitrite dissolved (N)	9	.18	.010-.050
Nitrogen, nitrate dissolved (N)	9	1.0	.41-2.1
Nitrogen, nitrite + nitrate dissolved (N)	13	1.3	.42-2.8
Phosphorus, dissolved (P)	4	--	<.01-.180
Phosphorus, ortho phosphates dissolved (P)	9	--	<.001-.100
Carbon, organic dissolved (C)	13	7.3	2.7-13.0
Hardness, (as $CaCO_3$)	39	660	330-1,700
Hardness, (as noncarbonate, $CaCO_3$)	38	319	.0-1,300
Calcium, dissolved (Ca)	39	119	69-230
Magnesium, dissolved (Mg)	39	88	37-280
Sodium, dissolved (Na)	39	326	71-960
Potassium, dissolved (K)	39	5.5	.9-17
Chloride, dissolved (Cl)	39	58	15-140
Sulfate, dissolved (SO_4)	39	939	220-2,600
Fluoride, dissolved (F)	22	.5	.3-1.0
Silica, dissolved (SiO_2)	39	8.9	5.8-14

Table 19.—Summary of chemical analyses of streamflow in Quitchupah Creek at station 09331900, water years 1979-81—Continued

	Properties and constituents	No. of analyses	Mean	Minimum-maximum
Milligrams per liter	Arsenic, dissolved (As)	11	—	<1-2.0
	Barium, dissolved (Ba)	2	150	100-200
	Boron, dissolved (B)	22	—	<20-700
	Cadmium, dissolved (Cd)	2	—	<1-2.0
	Chromium, dissolved (Cr)	9	—	<10-20
	Copper, dissolved (Cu)	2	—	<2-2.0
	Iron, dissolved (Fe)	22	—	<10-40
	Lead, dissolved (Pb)	8	—	<1-38
	Lithium, dissolved (Li)	11	119	40-180
	Manganese, dissolved (Mn)	22	—	4-30
	Mercury, dissolved (Hg)	2	—	<.1
	Nickel, dissolved (Ni)	2	—	2.0
	Selenium, dissolved (Se)	11	3.8	2.0-7.0
	Strontium, dissolved (Sr)	11	1,910	780-4,800
	Zinc, dissolved (Zn)	10	—	<3-20
	Phenols	12	—	<1-120

[1]Fixed-end-point determined by titration in the field.

Although Christiansen Wash is intermittent in its upper reaches, it is perennial at station 09331950. The annual mean flow at the station ranged from 2.09 cubic feet per second during water year 1981 to 6.42 cubic feet per second during water year 1984, with an average of 3.97 cubic feet per second (table 3). Most of the flow is during April-August (fig. 31), but the maximum peak flow was 1,540 cubic feet per second on September 8, 1981, which resulted from a thunderstorm.

The chemical quality of the flow in Christiansen Wash at station 09331950 is similar to that of the flow in Quitchupah Creek at station 09331900. Dissolved-solids concentrations in 46 streamflow samples collected from Christiansen Wash ranged from 450 to 4,500 milligrams per liter, with a mean of 2,440 milligrams per liter (table 20), and sodium and sulfate were generally the dominant ions. The maximum determined concentrations for lead, manganese, and selenium of 59, 300, and 60 micrograms per liter (table 20) exceeded the criteria of 50, 50, and 10 micrograms per liter established by the U.S. Environmental Protection Agency (1976, p. 5) for drinking-water supplies. The maximum phenol concentration was 22 micrograms per liter, compared to a criterion of 1 microgram per liter.

Suspended-sediment concentrations in 31 streamflow samples collected from Christiansen Wash at station 09331950 ranged from 79 milligrams per liter on September 21, 1980 to 15,200 milligrams per liter on September 8, 1981. Instantaneous suspended-sediment loads ranged from 1.6 to 326 tons per day during water year 1979, 0.83 to 70 tons per day during water year 1980, and 0.95 to 57 tons per day during water year 1981. Coal was 0.2 percent of the stream-bottom sediments.

Five samples of benthic invertebrates at station 09331950 during water years 1980 and 1982 had about the same diversity as those sampled by Lines and Plantz (1981, p. 53) during water year 1979. They all apparently reflected the generally poor chemical quality of the flow in Christiansen Wash as indicated in table 20 and discussed earlier. Four samples of phytoplankton at station 09331950 during water year 1981 showed fairly good diversity but also a fairly uniform distribution of blue-green algae (U.S. Geological Survey, 1982, p. 374). This probably also reflected the generally poor chemical quality of streamflow.

KANAB CREEK BASIN

Sink Valley Wash

Station 09403550 was operated in Sink Valley Wash during 1981 (pl. 1). Although the stream was dry during all visits to the station, gage-height record indicates that there were short periods of minimal flow on May 28, July 16, August 13, and 15, and September 6 and 14. The morphology of Sink Valley Wash indicates that the channel has carried large flows that resulted from intense thunderstorms.

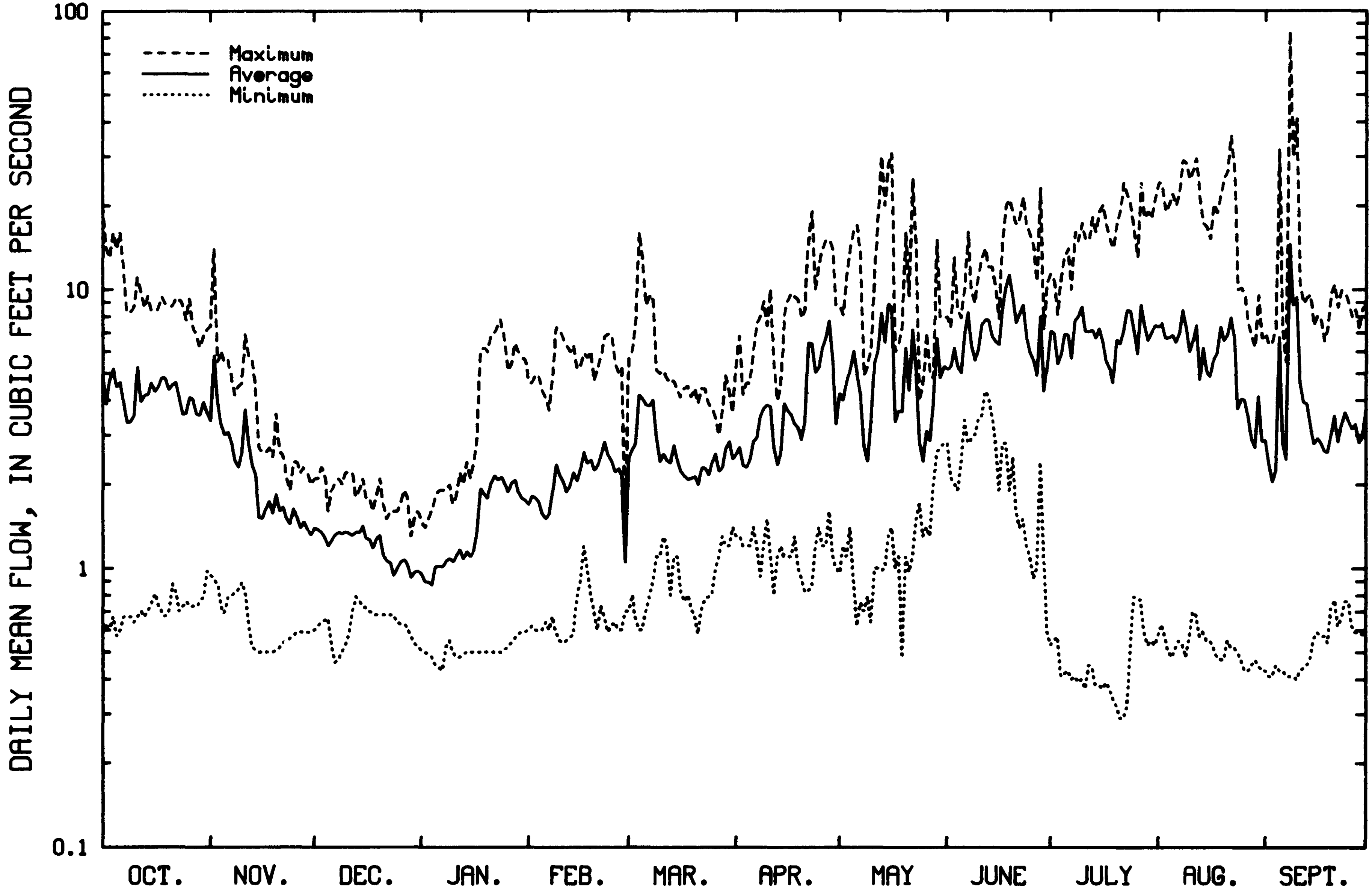

Figure 31.--Maximum, average, and minimum daily mean flow of Christiansen Wash at station 09331950, water years 1979-84.

Table 20.—Summary of chemical analyses of streamflow in Christiansen Wash at station 09331950, water years 1979-84

[< indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	47	4.1	0.40-24.0
Water temperature (degrees Celsius)	47	10.5	.0-24.0
Specific conductance (microsiemens per centimeter at 25° Celsius)	47	3,100	690-5,040
pH (units)	47	—	8.1-8.7
Sodium-adsorption ratio	47	4.6	1.0-8.0
Milligrams per liter			
Dissolved solids, sum of constituents	46	2,440	450-4,500
Oxygen, dissolved (O_2)	47	9.2	6.7-12.2
Carbon dioxide, dissolved (CO_2)	39	3.2	1.2-8.6
Alkalinity ($CaCO_3$)	39	420	180-2,600
Bicarbonate (HCO_3)[1]	39	432	210-860
Carbonate (CO_3)[1]	39	5.1	.0-18
Nitrogen, dissolved (N)	16	7.5	1.3-23
Nitrogen, organic dissolved (N)	9	1.4	.45-2.5
Nitrogen, ammonia dissolved (N)	9	—	<.01-0.140
Nitrogen, nitrite dissolved (N)	9	0.053	.030-.080
Nitrogen, nitrate dissolved (N)	9	9.1	1.6-23
Nitrogen, nitrite + nitrate dissolved (N)	21	6.8	.76-23
Phosphorus, dissolved (P)	12	—	<.01-.17
Phosphorus, ortho phosphates dissolved (P)	9	—	<.001-.030
Carbon, organic dissolved (C)	21	13.0	3.2-24
Hardness, (as $CaCO_3$)	47	1,090	280-2,100
Hardness, (as noncarbonate, $CaCO_3$)	39	788	.0-1,700
Calcium, dissolved (Ca)	47	165	53-340
Magnesium, dissolved (Mg)	47	166	35-310
Sodium, dissolved (Na)	47	356	40-710
Potassium, dissolved (K)	47	7.0	1.2-17
Chloride, dissolved (Cl)	47	52.6	7.3-150
Sulfate, dissolved (SO_4)	47	1,410	150-2,900
Fluoride, dissolved (F)	30	.49	.30-.70
Silica, dissolved (SiO_2)	47	10.6	5.5-16

Table 20.—Summary of chemical analyses of streamflow in Christiansen Wash at station 09331950, water years 1979-84—Continued

Milligrams per liter

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Arsenic, dissolved (As)	17	—	<1-2.0
Barium, dissolved (Ba)	5	--	<100-200
Boron, dissolved (B)	30	306	50-590
Cadmium, dissolved (Cd)	8	--	<1-6
Chromium, dissolved (Cr)	17	—	<10-20
Copper, dissolved (Cu)	8	1.9	1.0-3.0
Iron, dissolved (Fe)	30	—	<10-60
Lead, dissolved (Pb)	15	--	<1-59
Lithium, dissolved (Li)	14	197	51-370
Manganese, dissolved (Mn)	30	--	8-300
Mercury, dissolved (Hg)	8	—	<.1-.8
Nickel, dissolved (Ni)	8	--	<1-13
Selenium, dissolved (Se)	17	13.5	2.0-60
Strontium, dissolved (Sr)	14	1,700	530-3,400
Zinc, dissolved (Zn)	17	—	<3-94
Phenols	18	--	<1-22

[1]Fixed-end-point determined by titration in the field.

Thompson Creek

Thompson Creek originates on the Wasatch Formation of Tertiary age at an altitude of about 9,100 feet near the crest of the Pink Cliffs, southwest of Bryce Canyon National Park. It is a headwater tributary of Johnson Creek, the largest tributary of Kanab Creek that drains the Alton coal field. Thompson Creek drains strata of Tertiary and Cretaceous age, including the coal-bearing Tropic Shale of Cretaceous age.

Station 09403670 was operated on Thompson Creek during the 1981 water year (pl. 1, table 1). The daily mean flow in Thompson Creek at the station is illustrated in figure 32. The May-June flow was chiefly from snowmelt near the crest of the Pink Cliffs. The short-term increases in flow during June-September reflect thunderstorm runoff. Based on an indirect measurement made near station 09403670 on August 14, 1981, a thunderstorm produced a maximum peak flow of 1,030 cubic feet per second.

Chemical analyses of eight streamflow samples collected from Thompson Creek at station 09403670 during the 1981 water year are summarized in table 21. The dissolved-solids concentrations ranged from 1,100 to 1,800 milligrams per liter, with a mean of 1,400 milligrams per liter. Magnesium was generally the dominant cation, and sulfate was generally the dominant anion. None of the trace elements that were analyzed were found in concentrations that exceed the criteria established by the Environmental Protection Agency (1976) for drinking-water supplies. The maximum phenol concentration was 8 micrograms per liter, compared to a criterion of 1 microgram per liter.

Some of the geologic strata drained by Thompson Creek are easily eroded, therefore, potential annual sediment yields to Thompson Creek are large (U.S. Department of Agriculture, 1973). Sandberg (1979, p. 29) reported a maximum suspended-sediment concentration of 372,000 milligrams per liter in July 1977.

Suspended-sediment concentrations in seven streamflow samples obtained at station 09403670 during the 1981 water year ranged from 468 milligrams per liter on July 13, 1981, to 18,600 milligrams per liter on December 3, 1980. Instantaneous suspended-sediment loads ranged from 0.29 to 131 tons per day. The stream-bottom sediments consisted of about 0.4 percent coal.

Two of three phytoplankton samples collected at station 09403670 during the 1981 water year had a predominance of blue-green algae (U.S. Geological Survey, 1982, p. 407).

CONCLUSIONS

An objective of the monitoring program summarized in this report was to determine hydrologic impacts of future coal mining in coal fields of central and southern Utah. During the monitoring period of August 1978-September 1984, coal production nearly doubled at existing mines in the coal fields of central Utah, and there was no mining in the only coal field (Alton) of southern Utah included in the monitoring program. Data collected during the 6 water years of monitoring reflect the effects of both pre-monitoring mining and contemporary (water years 1979-84) mining. Stream-bottom sediments sampled at nearly all the monitoring sites contained small to moderate quantities of coal. This may be attributed chiefly to the pre-monitoring

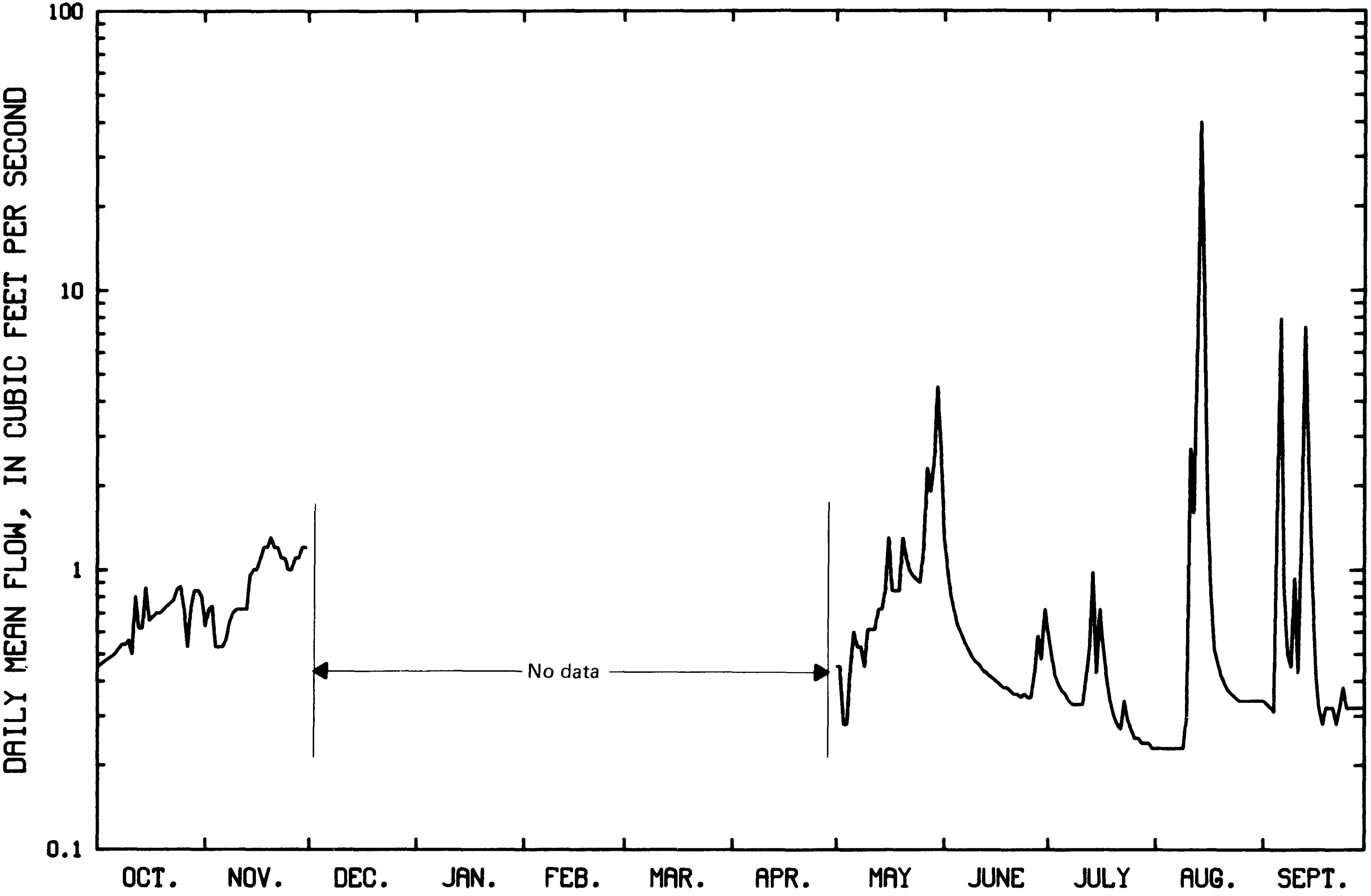

Figure 32.—Daily mean flow of Thompson Creek at station 09403670, water year 1981.

Table 21.—Summary of chemical analyses of streamflow in Thompson Creek at station 09403670, water year 1981

[< indicates actual value is smaller than the detectable value shown]

Properties and constituents	No. of analyses	Mean	Minimum-maximum
Streamflow (cubic feet per second)	8	0.65	0.15-2.6
Water temperature (degrees Celsius)	8	20.5	2.0-29.0
Specific conductance (microsiemens per centimeter at 25° Celsius)	8	1,830	1,440-2,250
pH (units)	8	--	8.1-8.4
Sodium-adsorption ratio	8	1.1	1.0-2.0
Milligrams per liter			
Dissolved solids, sum of constituents	8	1,400	1,100-1,800
Oxygen, dissolved (O_2)	8	7.3	6.2-10.9
Carbon dioxide, dissolved (CO_2)	7	2.4	1.4-3.1
Alkalinity ($CaCO_3$)	7	260	170-410
Bicarbonate (HCO_3)[1]	5	320	210-490
Carbonate (CO_3)[1]	7	1.4	.0-6.0
Nitrogen, dissolved (N)	3	.90	.86-0.97
Nitrogen, organic dissolved (N)	-	--	--
Nitrogen, ammonia dissolved (N)	-	--	--
Nitrogen, nitrite dissolved (N)	-	--	--
Nitrogen, nitrate dissolved (N)	-	--	--
Nitrogen, nitrite + nitrate dissolved (N)	3	.40	.17-.60
Phosphorus, dissolved (P)	3	.030	.010-.070
Phosphorus, ortho phosphates dissolved (P)	-	--	--
Carbon, organic dissolved (C)	3	5.1	3.7-7.0
Hardness, (as $CaCO_3$)	8	892	700-1,200
Hardness, (as noncarbonate, $CaCO_3$)	7	621	290-1,000
Calcium, dissolved (Ca)	8	137	96-220
Magnesium, dissolved (Mg)	8	134	94-160
Sodium, dissolved (Na)	8	88	61-120
Potassium, dissolved (K)	8	11.1	8.1-15.0
Chloride, dissolved (Cl)	8	22	17-30
Sulfate, dissolved (SO_4)	8	818	590-1,200
Fluoride, dissolved (F)	8	.4	.3-.5
Silica, dissolved (SiO_2)	8	9.2	8.1-10.1

Table 21.—Summary of chemical analyses of streamflow in Thompson Creek at station 09403670, water year 1981—Continued

	Properties and constituents	No. of analyses	Mean	Minimum-maximum
Milligrams per liter	Arsenic, dissolved (As)	3	1.3	1.0-2.0
	Barium, dissolved (Ba)	2	--	<100-100
	Boron, dissolved (B)	8	149	90-250
	Cadmium, dissolved (Cd)	3	--	<1-2.0
	Chromium, dissolved (Cr)	3	--	<10-10
	Copper, dissolved (Cu)	3	--	<2-4
	Iron, dissolved (Fe)	8	--	<10-30
	Lead, dissolved (Pb)	3	3.7	2-5
	Lithium, dissolved (Li)	2	105	100-110
	Manganese, dissolved (Mn)	8	19	8-40
	Mercury, dissolved (Hg)	3	--	<.1
	Nickel, dissolved (Ni)	3	--	<.1-4.0
	Selenium, dissolved (Se)	3	--	1
	Strontium, dissolved (Sr)	2	1,200	1,000-1,400
	Zinc, dissolved (Zn)	3	12.7	8-20
	Phenols	3	--	<1-8

[1]Fixed-end-point determined by titration in the field.

mining activities. Streamflow sampled at several sites contained large concentrations of sulfate and dissolved solids. Also, concentrations of various trace elements in streamflow at 10 sites, and of phenols in streamflow at 18 sites exceed the criteria of the U.S. Environmental Protection Agency for drinking water. This may be attributed to mine-drainage activities associated with the contemporary mining.

Another objective of the monitoring program summarized in this report was to obtain hydrologic data needed for a better definition or understanding of the hydrologic systems in the resource areas monitored. The large volume of data collected during the 6 water years of monitoring will help both the coal operators and regulatory agencies to better understand the hydrologic systems in their coal-resource areas of interest. The data also provide a more definite data-base with which to evaluate any adverse hydrologic impacts that might result from increased post-monitoring mining in those coal-field areas monitored.

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